# Partridge Lake
# Watershed Based Plan

Prepared for:

Partridge Lake Property Owners Association

Littleton, New Hampshire

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February 2008

*This document was developed through collaboration with the New Hampshire Department of Environmental Services and Partridge Lake Property Owners Association to guide the nonpoint source pollution reduction efforts to improve the water quality of Partridge Lake by reducing phosphorus and eliminating cyanobacteria. This restoration plan follows EPA Section 319 watershed plan guidelines and addresses each of the nine required components.*

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Acronyms and Abbreviations

| | |
|---|---|
| CN | curve number |
| CWA | Clean Water Act |
| DES | New Hampshire Department of Environmental Services |
| EPA | United States Environmental Protection Agency |
| ft | feet |
| gpd | gallons per day |
| ha | hectare, a unit of area equal to 10,000 square meters, equivalent to 2.471 acres |
| kg | kilograms |
| lbs | pounds |
| m | meters |
| mg/L | milligrams per liter |
| $mg/m^3$ | milligrams per cubic meter |
| NPS | nonpoint source |
| PLPOA | Partridge Lake Property Owners Association |
| ppb | parts per billion (equivalent to µg/L) |
| ppm | parts per million (equivalent to mg/L) |
| Tc | time of concentration |
| TMDL | Total Maximum Daily Load |
| TP | total phosphorus |
| TSS | total suspended solids |
| µg | micrograms |
| VLAP | Volunteer Lake Assessment Program |

## EXECUTIVE SUMMARY

Recent water quality data and observations at Partridge Lake in Littleton, NH have indicated algae (cyanobacteria) blooms, decreased water clarity, increased chlorophyll a concentrations, and hypolimnetic (bottom layer) oxygen deficits. The blooms of cyanobacteria (*Anabaena*) have prompted the New Hampshire Department of Environmental Services (DES) to list Partridge Lake on the 2008 Draft 303(d) list of impaired waterbodies. To reverse decreasing water quality trends and eliminate cyanobacteria blooms, watershed and internal phosphorus loading to Partridge Lake must be reduced.

To initiate the course of action for water quality improvements within Partridge Lake, the Partridge Lake Property Owners Association (PLPOA) applied to the DES in February 2006 for an EPA Section 319 Watershed Assistance and Restoration Grant. The grant application identified performance targets, milestones, and tasks required to remediate phosphorus loading within the watershed. Specifically, the PLPOA outlined the strategy it would implement prior to December 31, 2008 to address problems associated with stormwater runoff, septic systems, land use/development, and beach erosion that were contributing to the phosphorous loading and water quality problems within Partridge Lake.

This Watershed Based Plan will serve as a planning tool for the members of the Partridge Lake Watershed Partnership and municipal officials to identify watershed and in-lake pollutant reduction and water quality goals, and outline future planning, scheduling, and additional funding necessary to implement measures that will meet the water quality goals for Partridge Lake.

To improve water quality conditions in Partridge Lake, a goal of reducing external or watershed phosphorus loads by 25-30 percent has been established. In terms of actual loading this would translate into approximately 10.0 kg TP reduction annually, based on annual loading of 39.8 kg from surface and groundwater inputs (minus precipitation). This would result in an in-lake phosphorus concentration of approximately 11 μg/L as a future water quality goal. The current mean epilimnetic phosphorus concentration of Partridge Lake is 12 μg/L. The middle and lower layers of Partridge Lake, however, exhibit elevated phosphorus concentrations.

To achieve the phosphorus load reductions, several different phosphorus sources within the Partridge Lake watershed would need to be addressed. The specific watershed actions that would lead to a 25-30 percent phosphorus load reduction include:

- Implementing tributary, road, and shoreline best management practices (BMPs) to reduce sediment/nutrient loads from stormwater runoff;
- Replacing old and failing septic systems that may be directly discharging to Partridge Lake;
- Upgrading individual septic systems, by increasing the set-back distance to surface waters and constructing replacement septic systems where adequate soils with sufficient depth to bedrock and groundwater exist, to maximize phosphorus uptake by soils; and
- Educating watershed residents on practices that they can implement to reduce stormwater runoff and septic-based phosphorus contributions to Partridge Lake.

Upon implementation of the management measures to control watershed phosphorus loads, in-lake restoration may need to be considered to achieve the in-lake water quality goal. In addition to current watershed and in-lake restoration actions, future watershed actions such as zoning overlay and land conservation practices may be necessary to prevent an increase in phosphorus loads associated with development or redevelopment.

As part of the Watershed Based Plan, the Partridge Lake Watershed Partnership completed a septic survey for lakefront properties and will begin implementing selected BMPs outlined in the management plan. Septic survey results were used to target specific areas that may be contributing groundwater phosphorus loading to the lake. BMP design and construction will occur during the summer of 2008.

# 1 INTRODUCTION

## 1.1 Purpose

The purpose of this Watershed Based Plan is to outline a general strategy for the implementation of nonpoint source (NPS) pollution control measures in the Partridge Lake watershed to help restore the water quality of Partridge Lake, an impaired waterbody. Under the Environmental Protection Agency (EPA) National NPS 319 Program Guidance, States need a watershed-based plan meeting EPA guidance in order to use "incremental 319 funds" to implement management measures to help restore an impaired waterbody.

The Partridge Lake Property Owners Association (PLPOA) has been actively monitoring the water quality of Partridge Lake for more than 17 years through the Volunteer Lake Assessment Program (VLAP). Recently, the volunteer lake monitors and biologists from the New Hampshire Department of Environmental Services (DES) have noted algae (cyanobacteria) blooms, decreased water clarity, increased chlorophyll a concentrations, and hypolimnetic (bottom layer) oxygen deficits in Partridge Lake. The blooms of cyanobacteria (*Anabaena*) have prompted the DES to list Partridge Lake on the 2008 Draft 303(d) list of impaired waterbodies. Partridge Lake is currently listed (2006 303(d) list) for dissolved oxygen impairment. To reverse decreasing water quality trends and eliminate cyanobacteria blooms, watershed and internal phosphorus loading must be reduced. The logical sequence for restoring a waterbody is to first address watershed phosphorus loading prior to addressing the internal phosphorus loading.

To initiate the course of action for water quality improvements within Partridge Lake, the PLPOA applied to the DES in February 2006 for a Watershed Assistance and Restoration Grant. The grant application identified performance targets, milestones and tasks required to remediate Areas of Concern within the watershed that were identified in the Partridge Lake and Watershed Diagnostic Study (DES, 2007). Specifically, the PLPOA outlined the strategy it would implement prior to December 31, 2008 to address problems associated with stormwater runoff, septic systems, land use/development, and beach erosion that were contributing to the phosphorous loading and water quality problems within Partridge Lake.

## 1.2 Plan Scope

One of the performance targets identified in the grant application was to develop a Watershed Based Plan that outlined remediation measures for phosphorous reduction within the Partridge Lake watershed. The Watershed Based Plan, discussed herein, was developed in accordance with DES guidelines and is structured to address the required elements defined in the EPA guidance document entitled, "Handbook for Developing Watershed Plans to Restore and Protect Our Waters."

This plan supplements the Partridge Lake and Watershed Diagnostic Study (DES, 2007) by further examining the causes and sources of pollution within the watershed, and outlining remediation measures and monitoring efforts that will be implemented to ensure that improvements in the water quality of Partridge Lake are attained. A description of the Partridge Lake watershed is also included, largely reiterated from DES, 2007.

The scope of this plan describes recommended actions that can reasonably be accomplished through an on-the-ground effort within a ten-year timeframe (2007 to 2016) in the Partridge Lake watershed. This plan integrates the analysis and recommendations presented in the Partridge Lake Diagnostic Study (DES, 2007), which outlines the need for a reduction in watershed based sources of phosphorus in order to address actual in-lake total phosphorus (TP) concentration and the potential in-lake treatment (to reduce internal loading).

In order to track the implementation of this plan and to help measure progress towards achieving its goals and objectives, the recommendations are presented in a temporally phased approach. Throughout this plan, actions and goals will be referred to in three phases:

- Phase 1 refers to the immediate and short-term actions associated with this plan; Phase 1 tasks should be completed by the end of 2008.

- Phase 2 refers to mid-term actions and may require more detailed study or coordination. This phase generally refers to actions that should be performed from 2009 through 2011.

- Phase 3 refers to longer term action and goals for which prerequisites are needed. For the purpose of this document, Phase 3 refers to activities in the watershed that may take place five to ten years from now.

## 1.3 Water Quality Objectives

The primary goal of this plan is to remove Partridge Lake from the State's 303(d) list of impaired waterbodies. To meet this goal, the initial objective of reducing external phosphorus loading to Partridge Lake has been established. This will in turn reduce or eliminate cyanobacteria blooms allowing the lake to meet New Hampshire's Water Quality Standards.

Through the initial phase of this project, the target for reduction of watershed inputs (from surface water and groundwater) of phosphorus is 25-30%. In terms of actual loading this would translate into approximately 10.0 kg TP reduction annually. This target was determined through discussions with DES personnel, and an evaluation of the modeling predictions (e.g., Vollenweider, Dillon-Rigler) presented in DES, 2007. The loading reductions would result in an in-lake phosphorus concentration of approximately 11 µg/L as a future water quality goal. The phosphorus load reduction and in-lake phosphorus water quality goal is based in part on an empirical method known as the Vollenweider Relationship, which predicts the lake's trophic status (the degree of lake aging or nutrient status of a lake) as a function of the areal phosphorus loading. The model also predicts in-lake phosphorus concentrations. The relationship was developed by assessing a large number of lakes for which a linear relationship between the log of the phosphorus loading and the log of the ratio of the lake's mean depth to hydraulic residence time was established. Using the characteristics of Partridge Lake, a phosphorus load reduction of 25-30% was proposed that will likely allow the lake to meet water quality goals by reducing in-lake phosphorus concentrations.

The specific actions that will be investigated to achieve these water quality objectives include:

- Implement Best Management Practices (BMPs) to reduce sediment/nutrient loads from stormwater runoff;
- Replace old and failing septic systems and examine alternatives;
- Educate watershed residents on practices that they can implement to reduce phosphorus contributions to Partridge Lake; and
- Examine steps that can be taken to control the internal loading of phosphorus in Partridge Lake once the external sources of phosphorus are reasonably controlled.

## 1.4 Watershed Description

Partridge Lake is a naturally occurring lake located within the town of Littleton, Grafton County, New Hampshire (Figure 1-1). The lake is impounded at the southwest end by a three foot high concrete dam and has a surface area of 104 acres (42.05 hectares), a perimeter of 2.8 miles (4,500 m), a maximum depth of 50 ft. (15.2 m), and a water volume totaling 85,955,900 cubic feet (2,434,000 $m^3$). The lake characteristics are summarized in Table 1-1. For a comprehensive description of the watershed, refer to DES, 2007.

The drainage area for Partridge Lake is approximately 1.33 square miles (344 hectares) and encompasses portions of the towns of Littleton and Lyman in northwestern New Hampshire. In addition to Partridge Lake, the watershed contains a few wetland areas, which comprise an area of approximately 22 acres. Precipitation, tributary flow, overland flow (not specific to any one tributary), and groundwater seepage constitute the hydrologic inputs to Partridge Lake. Tributaries include five year-round streams and several seasonal streams. The subwatersheds are presented in Figure 1-2. The outlet of Partridge Lake flows in a southwesterly direction from the lake and eventually enters Dodge Pond to the south.

The climate of this region is characterized by moderately warm summers, cold, snowy winters, and ample rainfall, which is typically acidic. Generally, snow is present from mid-December to the end of March or early April. Ice-out for the lake usually occurs in mid-April.

Partridge Lake is located in the EPA's Nutrient Ecoregion 58 - Northeastern Highlands. The Northeastern Highlands comprise a relatively sparsely populated region characterized by nutrient poor soils blanketed by northern hardwood and spruce fir forests. Land-surface forms in the region consist of low mountains in the southwest and central portions to open high hills in the northeast. Many of the numerous glacial lakes in this region have been acidified by sulfur depositions originating in industrialized areas upwind from the ecoregion to the west. The range of reference conditions for total phosphorus in lakes in this ecoregion is 7-10 µg/L. For comparison purposes, the mean total phosphorus concentration in the metalimnion of Partridge Lake is 20 µg/L based on data collected since 1986.

Partridge Lake is listed as a Warmwater Fishing body of water in the NH Atlas and Gazetteer and is listed by the NH Fish and Game Department as a suggested fishing location for chain pickerel, largemouth bass, northern pike, rock bass, and smallmouth bass in the Great North Woods Region of the State. The lake is predominately used by lake residents, transient boaters, and fishermen.

There are three types of rock found in the Littleton area: granite, metamorphic rock (which often contain minerals such as feldspars, quartz, garnets, and graphite), and slate and sandstone. Soils within the watershed are comprised of a mix of Berkshire loams, Marlow and Peru fine sandy loams, and Tunbridge-Lyman rock outcrops (Figure 1-3). Loamy sand of the Colton, Adams, and Waumbek families, and Monadnock and Hermon soils are also found in the watershed. In general, soil permeability is rapid throughout the watershed. Depth to bedrock in most areas of the watershed is shallow, and ranges from 0.5 to 1.6 meters (1.6 to 5.2 feet). Depth to groundwater is 2 meters (6.6 feet) or greater in most areas of the watershed (DES, 2007).

Approximately 75 % (711 acres) of the land use within the Partridge Lake watershed is characterized as mixed forest. Residential development comprises 71.8 acres (7.6 %) of the watershed area. Areas of low intensity residential development occur along most of the Partridge Lake shoreline. Development in the Partridge Lake watershed is generally characterized by seasonal cottages along the shoreline, with larger year round homes located farther back from the lake edge. Topography of the watershed is presented in Figure 1-4.

**Table 1-1: Characteristics of Partridge Lake, NH.**

| **Parameter** | **Lake Information / Morphometric Data** |
|---|---|
| Lake Name | Partridge Lake |
| Town | Littleton |
| County | Grafton |
| River Basin | Connecticut |
| Latitude | 44°18’28”N |
| Longitude | 71°53’16”W |
| Elevation (ft) | 846 |
| Shoreline Length (meters) | 4,500 |
| Watershed Area (ha) | 344 (850 acres) |
| Lake Area (ha) | 42.05 (104 acres) |
| Maximum Depth (m) | 15.2 |
| Mean Depth (m) | 5.8 |
| Volume ($m^3$) | 2,434,000 |
| Areal Water Load (m/yr) | 3.65 |
| Flushing Rate ($yr^{-1}$) | 0.6 |
| Phosphorus Retention Coefficient | 0.71 |
| Lake Type | Natural with dam |

Source: DES, 2007

## 1.5 Prior Work

### *1.5.1 Volunteer Lake Assessment Program*

New Hampshire's Volunteer Lake Assessment Program (VLAP) is a cooperative program between the DES and lake residents and lake associations. The program was initiated in 1985 and serves a dual purpose by establishing a regular volunteer-driven lake sampling program to assist the DES in evaluating lake quality throughout the state, and by empowering volunteer monitors and lake residents with information about the health of their waterbody. This cooperative effort allows biologists and lake associations to make educated decisions regarding the future of New Hampshire's lakes and ponds.

Partridge Lake was added to VLAP in 1989 and the PLPOA has been actively monitoring water quality in the lake for over 17 years through this program. As part of this program, data is collected on parameters such as temperature, dissolved oxygen, chlorophyll a, *E. coli* bacteria, water transparency, turbidity, total phosphorous in the epilimnion (top layer), metalimnion (middle layer), and hypolimnion (bottom layer), species of phytoplankton, pH, acid neutralizing capacity, and conductivity.

Data was collected from the lake and various tributaries by volunteer sampling three times in 2006 - once each in June, July, and August. An algal bloom was observed in November 2006; an additional water quality sample was collected from the lake deep spot at that time. Hypolimnetic TP ranged from 0.092 mg/L in June (under thermally stratified conditions) to 0.020 mg/L in November (under non-stratified conditions). Comparing the epilimnetic samples taken in August and November, TP increased from 0.007 mg/L to 0.026 mg/L. Chlorophyll a concentrations subsequently increased from 3.99 mg/m$^3$ to 13.73 mg/m$^3$. The data appear to confirm the theory that fall mixing is redistributing the phosphorus bound in sediments in the hypolimnion throughout the lake and likely triggering a surface algal bloom.

According to VLAP monitors, late summer and early fall algal blooms have been observed over the past few years in the lake. These algal blooms, along with other observations of water quality such as decreases in Secchi depth readings, increases in chlorophyll a concentrations, and decreases in oxygen concentrations within the hypolimnion, led the DES to conduct a diagnostic study within the lake.

### *1.5.2 DES Diagnostic Study*

Due to declining water quality conditions observed through the VLAP, DES biologists conducted a 1-year diagnostic study of Partridge Lake from June 1, 2000 to May 31, 2001. The goals of this study were to gain more information about the lake and its watershed, to determine sources of phosphorous within the watershed, and to make recommendations for the overall enhancement and protection of Partridge Lake through watershed management and/or in-lake restoration.

The study involved constructing a hydrologic and phosphorous budget, conducting an anonymous septic system survey, determining the lake's trophic status, and evaluating a number of biological and physical parameters such as temperature and dissolved oxygen levels, pH and acid neutralizing capacity, conductivity, turbidity, phytoplankton communities, chlorophyll a, transparency, and the distribution of aquatic plants.

The water budget quantified hydrologic inputs (e.g., precipitation, tributary, direct runoff and groundwater) and outputs (e.g., evaporation, outflow, and groundwater recharge) to determine the major hydrologic sources to Partridge Lake. Results of the analysis showed that inputs from overland runoff (including gauged and un-gauged tributaries) contributed the greatest quantity of water to Partridge Lake

(62 %), followed by groundwater inputs (24 %), and direct precipitation (14 %). Further analysis of the overland runoff revealed that sub-watersheds with year-round tributaries contribute the greatest source of overland flow to the lake (41 %), while those sub-watersheds with un-channelized inputs or seasonal inputs contributed a total of 21 % of the overland runoff. Of these tributaries, Tributary J was the largest contributor (34 %), followed by Tributary A (21 %), Tributary G (19 %), and Tributary H (15 %). Figure 1-2 shows a map of Partridge Lake Subwatersheds.

The diagnostic study also quantified the phosphorous budget for Partridge Lake by multiplying measured total phosphorous (TP) concentrations by the respective hydrologic inputs and outputs. The analyses of external phosphorous inputs into Partridge Lake revealed that near-shore groundwater inputs represented the largest input of phosphorous (44% or 23.4 kg TP) during the study period followed by overland runoff (31% or 16.4 kg TP), and wetfall / dryfall precipitation (25% or 13.1 kg TP).

The internal loading of phosphorous is also considered to be a significant bioavailable source during certain times of the year. DES noted that it is difficult to quantify the actual amount of phosphorus released into the water column from lake sediments; however, that does not underscore its importance. The total phosphorus range for the summer epilimnetic values for New Hampshire lakes ranges between <1 and 121 µg/L, with a median value of 12 µg/L. The total phosphorus concentration in the metalimnion (thermocline) layer also falls within the mean range, with a mean concentration of 20 µg/L, however this concentration is more conducive to fostering chlorophyll a production and algal blooms. In the bottom layer of the lake, or hypolimnion, the total phosphorus concentration is considered excessive, with a mean summer concentration of 293 µg/L (a concentration greater than 40 µg/L is classified as excessive by the DES).

Generally, the in-lake total phosphorus concentration can be an indicator of its trophic status, as shown in Table 1-2. Trophic states of ponds can range within and between three basic categories: oligotrophic, mesotrophic, and eutrophic. In 2001, Partridge Lake received 11 trophic points and was classified as mesotrophic. The Dillon/Rigler Model classifies a lake as oligotrophic, mesotrophic or eutrophic by comparing calculated annual loadings with permissible annual loadings. These calculations were performed to determine Dillon/Rigler Trophic Status for Partridge Lake with and without internal loading. The solution of the Dillon/Rigler equation for Partridge Lake data shows the existing trophic status of the lake as oligotrophic if internal loading is not entered into the equation. A more realistic look at Partridge Lake, however, must take into account this internal source of phosphorus, and thus, based on this, the lake would then be classified as mesotrophic (DES, 2007).

**Table 1-2: Lake Phosphorus Concentration as an Indicator of Trophic Status.**

| Phosphorus Concentration (µg/L) | Trophic Category |
|---|---|
| < 10 | Oligotrophic |
| 10 - 20 | Mesotrophic |
| > 20 | Eutrophic |

Analysis of the total phosphorous concentration data shows that as the summer progresses, internal phosphorus loading from the bottom sediments is a major contributor to the lake's nutrient budget. During the summer, internal loading occurs when the hypolimnion loses oxygen. This lack of oxygen causes a chemical reaction in the sediments that ultimately results in the release of phosphorus into the water column (known as internal loading). For example, total phosphorous concentrations were greater than 200 µg/L during most of the summer sampling events in 2000.

Analysis of total phosphorous concentration within Partridge Lake since it was added to VLAP in 1989 demonstrates that concentrations within the hypolimnion are excessively high and have been consistently higher than those in the epilimnion. Moreover, these concentrations have been particularly elevated during the past 10 years and the internal loading phenomena described earlier is suspected to be the cause of the cyanobacteria blooms that have been observed in recent summers.

Through review of the data collected during the diagnostic study, the DES determined that certain activities that were occurring within the watershed may be contributing to a decrease in water quality. The lake was classified as borderline between advanced mesotrophic and early eutrophic conditions, which indicates that the lake is showing signs of impact, and that the aging of the lake may be accelerated because of those impacts.

DES documented certain activities around the watershed that may be contributing to decreases in water quality over time, and formulated a number of recommendations to help maintain the lake's current trophic status and potentially increase the water quality through conscientious and proactive watershed management. These areas of concern are discussed in more detail throughout this plan.

**Figure 1-1: Partridge Lake Watershed.**

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**Figure 1-2: Partridge Lake Subwatersheds.**

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**Figure 1-3: Soil Types in the Partridge Lake Watershed.**

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**Figure 1-4: Partridge Lake Watershed Topography.**

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# 2 CAUSES AND SOURCES OF NONPOINT SOURCE POLLUTION

Partridge Lake has been listed on the 2006 Draft 303(d) List as impaired due to dissolved oxygen conditions that lead to blooms of cyanobacteria. The suspected cause of these blooms is due to the internal nutrient loading of phosphorous during hypolimnetic anoxic events that occur within the lake.

Partridge Lake is influenced by two distinct types of phosphorus loading that occur during certain times of the year: internal loading and external loading. Phosphorus is a key nutrient influencing plant growth in lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form. Under certain conditions particulate phosphorus can be converted to soluble reactive phosphorus.

Internal loading occurs when phosphorus builds up in lake sediments and is released into the deepest parts of the water column. When sufficient water circulation or "turnover" of the lake occurs, the elevated phosphorus levels are circulated throughout the water column which can lead to algal blooms in areas with sufficient light penetration. This phenomenon is particularly common in the late summer and fall months.

External loading is the introduction of total phosphorus from all other sources within the watershed. The phosphorus from external sources mixes with lake waters and, if in dissolved form, is immediately available to support algae growth. The remainder of the particulate phosphorus settles to the bottom of Partridge Lake. Some of it settles quickly in its particulate form while a portion may be converted to dissolved phosphorus, used by plants and other organisms. As these plants and organisms die, organic and condensed phosphorus settles to the lake bottom. When this settling action happens, external loading can contribute to internal loading as more phosphorus is added to the lake sediments, and under the right conditions can be released as dissolved phosphorus. External loading must be controlled to prevent internal loading from increasing.

The DES Diagnostic Study quantified three primary external pathways for total phosphorus to enter Partridge Lake: groundwater (44%), surface run-off (31%), and precipitation (25%). Once the targeted watershed sources of phosphorus are addressed (25-30% reduction), attention can be focused on in-lake remediation.

The major sources of phosphorus pollution sources to Partridge Lake are discussed below. The following sub-sections are a summary of our analysis building upon the recommendations in the DES Diagnostic Study. Note that the recommended management measures to address these sources are presented in Section 3, and the load reduction estimates are provided in Section 4 of this Plan.

## 2.1 Phosphorus in Groundwater

Groundwater is the largest external phosphorus source to Partridge Lake. Suspected causes of phosphorus inputs to groundwater are likely due to the presence of septic systems in close proximity to the lake, in conjunction with the soil, bedrock and water table characteristics around Partridge Lake. All of the homes around Partridge Lake are on subsurface systems or holding tanks. Phosphorus loading problems are common in areas with older systems, highly permeable soils (e.g., sands), mineral-poor soils, nearby surface waters, and high system densities.

A number of factors can influence the shape and movement of contaminant plumes from septic systems. Climate, soils, slopes, landscape position, geology, regional hydrology, and hydraulic load determine whether the plume will disperse broadly and deeply or, more commonly, migrate in a long and relatively narrow plume along the upper surface of a confining layer or on the surface of the groundwater (EPA, 2002a).

The soil survey indicates that there are limitations for septic system use based on shallow depth to bedrock in many areas of the watershed, and also due to highly permeable sandy soils throughout the area. The soil types and depth to bedrock (e.g., 0.5 to 1.6 m) around most of the watershed is allowing water that infiltrates into the soil to travel rapidly down gradient toward the lake.

The age of septic systems compounded with the soil characteristics likely lead to ineffective treatment of septic nutrients before the septic leachate enters into the groundwater. DES noted that this leachate, coupled with phosphorus release from decaying organic matter, are rapidly picked up in shallow groundwater moving towards the lake, and are deposited near-shore in groundwater seepage to the lake.

The PLPOA has estimated that there are approximately 68 dwellings in the immediate vicinity of the lake's edge (i.e., within 300 feet); 19 of these properties are considered to be year-round dwellings, whereas the remaining 49 are seasonal. Analysis of data from the DES diagnostic study revealed that the largest source of phosphorus to Partridge Lake resulted from near-shore groundwater seepage inputs (e.g., 44% or 23.4 kg TP) and that septic systems likely have the largest influence on the amount of total phosphorus entering the lake. All of the properties around the lake are on subsurface systems as there is currently no centralized sewer system in place to service this area. Analysis of results from the septic system survey conducted around Partridge Lake in 2001 show that 36% of the septic systems were more than 20 years old and have reached or exceeded their designed life span. The septic survey conducted in 2007 revealed that 42% of septic systems are currently more than 20 years old.

The 2007 septic survey results are presented in detail in Appendix 1. The results provide a clearer picture of the septic system conditions and distribution of lake residents. Table 2-1 shows the distribution of the septic system setback distances of the respondents to the 2007 survey.

**Table 2-1: Septic System Setback Distances in the Partridge Lake Watershed.**

| Setback Distance (feet) | Number | Percentage of Total |
|---|---|---|
| 0-50 | 4 | 10% |
| 51-100 | 16 | 41% |
| 101-150 | 14 | 36% |
| 151-200 | 3 | 8% |
| 201-250 | 1 | 3% |
| 250+ | 1 | 3% |
| **Total** | 39 | 100% |

Management measures to address groundwater loading are presented in Section 3 and the associated load reductions are presented in Section 4.

## 2.2 Stormwater Runoff

The second largest contributor of phosphorous to Partridge Lake is from surface runoff or stormwater runoff within the watershed. These inputs accounted for 31 % (16.4 kg TP) of the total phosphorus load to Partridge Lake. In general, the residential development around lakes and ponds can lead to increases in the volume and rate of stormwater runoff as development occurs in a watershed. This, in turn, can lead to significant increases in phosphorus loading which can result in degradation of the surrounding surface waters.

Based upon the results and observations made during the DES Diagnostic Study, and subsequent site investigations, specific problem areas of concern with regard to stormwater management within the Partridge Lake watershed were identified. Phosphorus load sources from stormwater include increased runoff in the subwatersheds and tributaries, and road runoff.

*Subwatershed and Tributaries*

1. The DES report quantified the stormwater input of phosphorous from gauged and ungauged tributaries during their diagnostic study. The gauged tributaries accounted for 21 % (10.9 kg TP) of the total phosphorous load, whereas the ungauged tributaries accounted for 10 % (5.5 kg TP) of the total input. Of the gauged tributaries, Tributary J was the highest contributor of phosphorous (3.9 kg TP, 24 % of gauged tributary contribution), followed by Tributary G (2.9 kg TP, 18 %), and Tributary A (2.6 kg, 16 %) respectively. Figure 2-1 shows the relative percent phosphorus contributions from each subwatershed based upon the data collected in 2000-2001.

*Roads*

1. Runoff from Old Partridge Lake Road. This is a steeply sloping hill with a paved road, within the drainage area of Tributary A, that meets Partridge Lake Road at the shoreline of the lake. Snowmelt and runoff travel down this hill carrying sediment, cross Partridge Lake Road, and erode sandy shoreline sediments adjacent to the lake and Tributary A.
2. Drainage ditches along Partridge Lake Road. Dirt drainage ditches exist along most of the shoreline roads. Some of these have culvert connections to the lake, sending turbid water into the shallows of the lake. Some ditches, however, are filled with sediment and road sand.
3. Winter Sand. To further exacerbate the runoff problem, sediment left on the road after winter maintenance activities is likely getting washed into the lake. Field observations verify that the main roads along the lake contain sand deposits along the edges. Stormwater runoff can also pick up phosphorus bound to sediment and other materials such as road sand and carry this material into the lake.

## 2.3 Shoreline and Beach Erosion

The shoreline of Partridge Lake contains a few beaches that are occasionally replenished with fresh sand. During the DES diagnostic study, observable problems were noted with many of these beaches. Particularly, sand beaches are potentially damaging to the lake due to the filling in of shoreline habitat and the introduction of nutrients into the lake (phosphorus binds to sediment particles). Shallow areas newly created by beach erosion allow for greater areas of sunlight penetration, and may also encourage even more abundant plant establishment along the shoreline areas of the lake. Areas of the lakebed near eroding beaches often show signs of sedimentation. As new layers of sand cover shoreline habitat, the macroinvertebrate communities, fish spawning areas, and amphibian habitat may be smothered or destroyed.

In addition to beach erosion, there are areas of the Partridge Lake shoreline that are steeply sloped and are either actively eroding or susceptible to erosion, largely due to overland runoff. The presence of roads with steep shoulders adjacent to the lakeshore can exacerbate the erosion areas. Erosion of the lake shoreline can lead to similar problems as described above, which can be intensified during storm events.

## 2.4 Internal Phosphorous Loading

Internal loading occurs when the bottom of the lake loses oxygen, causing a chemical reaction in the sediments that ultimately results in the release of phosphorus to the water column. As the bottom waters lose oxygen during the summer months internal loading occurs. This process adds to the overall phosphorus available for algae growth in the lake, and is likely the cause of the occasional algae bloom that Partridge Lake has experienced in recent summers.

Internal loading of phosphorous within Partridge Lake is considered to be significant during certain times of the year. During the Diagnostic Study period lake stratification developed over the course of the summer. This stratification resulted in depleted oxygen concentrations within the hypolimnion (bottom layer), which in turn resulted in increased concentrations of total phosphorus in the hypolimnion.

DES noted that it is difficult to estimate the actual amount of phosphorus released into the water column from lake sediments. The actual amount of phosphorus released into the water column of the lake from the sediments through internal loading is a significant phosphorus contributor to Partridge Lake. Through analysis of hypolimnetic phosphorus concentrations, the average annual internal phosphorus load in Partridge Lake was estimated as 70 kg/year (A. Chapman, DES, pers. comm.). This is more than all the external phosphorus sources to the lake combined (52.8 kg).

## 2.5 Agricultural Operations

Although there is a small percentage of agriculture land within the Partridge Lake watershed, the types of operations (horse and cow pastures) have the potential to affect water quality if not carefully managed. There is one active horse pasture within the Partridge Lake watershed (Figure 2-2). The total area equals approximately 20 acres. The average horse generates 50 pounds of manure per day (Lawrence, et al., 2003). Many of the nutrients ingested by pasturing animals return to the environment in feces and urine. If the waste is allowed to enter streams and lakes through runoff, excessive amounts of these same nutrients can stimulate unwanted algae blooms and degrade water quality.

There is also an old diary farm in the watershed which currently only pastures 10-12 young cows in the summer. This area in the past was a fully operational dairy farm, which at one time had approximately 80 cows. The area of the farmland is approximately 53 acres. This represents only a small percent of the total watershed area; however, these areas could have a historical impact on phosphorus loading into the lake. An average dairy cow generates 65 pounds of manure per day. Using general approximations of nutrient content in dairy cow manure, 80 cows can generate over 900 kg of phosphorus per year. The manure was probably spread onto the fields as fertilizer. The conversion of this farm into pasture land only may reduce the amount of phosphorus into this subwatershed. To verify this, the tributaries associated with the subwatersheds that contain this former dairy operation (Tributary G, in particular) should be re-sampled for phosphorus concentrations and compared to the data collected in 2000-2001 by DES.

**Figure 2-1: Partridge Lake Annual TP Loading per Subwatershed (based on 2000-2001 data).**

Attached as .pdf

**Figure 2-2: Agricultural Areas in the Partridge Lake Watershed.**

Attached as .pdf

# 3 NONPOINT SOURCE MANAGEMENT MEASURES

This section contains recommendations for implementing management measures to control nonpoint source pollution in Partridge Lake watershed. The DES Diagnostic Study provided several recommended NPS management measures to address the water quality problems of Partridge Lake. These recommendations are examined further and discussed in more detail here. The potential BMPs will be evaluated taking into account the goals of the plan, capital costs, operation and maintenance costs, benefits and other factors including property ownership.

## 3.1 Groundwater BMPs

*Recommendation: Pursue improvements to individual septic systems and consider alternatives such as a community system.*

The soil survey for the area around Partridge Lake indicates that there are limitations for septic system use based on shallow depth to bedrock in many areas of the watershed, and also due to highly permeable sandy soils throughout the watershed (DES, 2007). DES reported an annual groundwater loading of 24.3 kg/year to Partridge Lake, which represents 44% of the total external inputs of phosphorus to the lake. The objective of reducing nutrients from septic systems throughout the watershed, particularly those closest to the lake shoreline or its tributaries within the 250 feet of the lake, will facilitate meeting the overall phosphorus load reduction target.

The options for addressing the phosphorus loading to groundwater include: 1) Homeowner education and initiative, 2) Implementation of a group maintenance schedule, 3) Individual retrofits such as high-iron sand filters, or 4) Community or cluster system.

### *3.1.1 Homeowner Education*

As part of the DES Diagnostic study, an anonymous septic system survey was conducted within the watershed during the summer of 2001. Another septic survey of Partridge Lake watershed residents was conducted in July 2007 in which 75 paper surveys were sent out. Of those, 49 completed surveys were received for a 65% return rate (Figure 3-10 shows the location of those who completed the surveys).

The results of the septic system survey reported that the approximate age of septic systems around the lake ranged from less than 5 years old to greater than 25 years old. The estimated life span of a state approved septic system in New Hampshire is between 15 and 20 years, providing that the system is used within the design specifications. Analysis of these results showed that approximately 90 % of the responders indicated that their septic systems were either new, operating well, or adequate; however 42% of respondents indicated their system was more than 20 years old. The complete results of the 2007 septic survey are contained in Appendix 1.

The results of the recent septic survey support the idea that phosphorus in groundwater is the primary problem affecting external loading to Partridge Lake. The septic/groundwater phosphorus loading interaction at Partridge Lake is primarily a result of septic system position in relation to Partridge Lake, shallow groundwater table, and limiting soils as opposed to neglect of system maintenance or low pumping frequency.

The data obtained relative to system usage and loading can be used to estimate load reduction estimates (as described further in Section 4) and target management measures.

In addition, the Lake Guide disseminated in the summer of 2007 highlighted the benefits of a healthy septic system. Educational activities directed at increasing general awareness and knowledge of onsite management efforts can improve the probability that simple, routine operation and maintenance tasks (e.g., inspecting for pooled effluent, pumping the tank) are carried out by system owners (EPA, 2002a).

### *3.1.2 Group Maintenance*

The recent septic survey indicated that 58% of respondents pump their septic tanks every two years on average, and 100% pump at least every 5 years. According to DES, accumulated sludge should be pumped out every one to three years for shorefront residents, and every 3-5 years for other dwellings farther back in the watershed. Even though septic pumping frequency at Partridge Lake is within DES recommendations, more frequent pumping may be beneficial in certain areas around the lake. An option to address this would be to requests bids from septic tank pumping contractors to perform the inspection and pump out certain tanks at a set rate and interval. This can be done by PLPOA as a follow-up to the septic survey.

### *3.1.3 Upgrade Individual Systems/Retrofits*

The upgrading of old or failing septic systems could occur through four channels:

- Voluntary replacement;
- Proven failure and subsequent order to replace the system from the health officer or DES;
- Conversion from seasonal to year-round use or addition of bedrooms; or
- Engineering study required by New Hampshire state law conducted prior to the house sale showing evidence that the septic system was in need of repairs or replacement.

New Hampshire Revised Statutes Annotated 485-A:2 defines failure as “the condition produced when a subsurface sewage or waste disposal system does not properly contain or treat sewage or causes or threatens to cause the discharge of sewage on the ground surface or into adjacent surface or groundwater.” To ensure prompt and effective replacement of a failed subsurface system, the local official responsible for health code enforcement must prepare a written statement verifying that the existing system is in failure. This statement must be submitted to DES with the application to replace the existing system.

Other options include providing low-interest loans to homeowners to pay for repairs and replacement systems or developing ordinances to mandate improvements when a septic system is failing. This would require additional manpower resources for diagnosing the problem, and prescribing corrective actions.

It has been reported that if phosphorus from septic tanks causes groundwater contamination, it is possible to reduce the phosphorus concentration in system effluents through chemical additions such as aluminum phosphate, lime or ferric chloride to septic tanks (Canter and Knox, 1985). However, few phosphorus removal processes are well developed for onsite wastewater systems application. Those that have been successfully applied generally fall into the categories of chemical, physical, and biological systems. The high maintenance of the phosphorus attenuation applications has limited their effectiveness and use.

Phosphorus is rarely designed to be removed in onsite pretreatment because most soils have the innate ability to adsorb the nutrient for many years before it begins to migrate to nearby ground or surface waters. However, as onsite system sites age, there is the potential for serious environmental degradation, as witnessed by the thousands of inland lakes where older onsite development is increasingly being cited as the primary reason for lake eutrophication (EPA, 2002a). In these cases effluent filters on the outlets of septic tanks may help to control phosphorus in effluent. Individual systems will have to be evaluated on a case-by-case basis to determine appropriateness of the potential retrofit. Additional recommendations for wastewater treatment alternatives are presented in DES, 2007.

### *3.1.4 Community or Cluster System*

*Recommendation: Reserve/acquire land areas for potential cluster septic systems for future analysis.*

The Littleton Wastewater Treatment Plant is located on Meadow Street in Littleton, approximately 5 miles away from Partridge Lake. The nearest sewer connection to the lake is in the area of the Littleton Hospital, approximately 2.5 miles away. Connecting Partridge Lake residents to the town sewer is most likely cost prohibitive. Cluster systems are innovative systems that collect and treat sewage for many homes or groups of homes around a lake. First tier development around Partridge Lake could elect the alternative of a subsurface treatment system with conventional collection from clusters or groups of individual homes. These cluster systems are usually simple and cost effective alternatives for the secondary treatment of small flows. Installations are suitable for discharge volumes of 500 gpd to 300,000 gpd. Small areas of land (perhaps shared lots or open lots) are necessary for the installation of such systems; therefore the availability of land for this application may be a limiting factor.

A centralized sewage treatment system may be feasible for Partridge Lake. These systems must be designed carefully given the concentrated amount of sewage material, as leachate from cluster systems may still pose threats to groundwater. There is limited land in the immediate vicinity of Partridge Lake available for a potential cluster sewage system due to existing development and site topography. There is vacant land away from the lake which may serve to accommodate a cluster system. Two options for clusters systems are presented in Section 4. Further study would be required to determine the feasibility of each cluster system option.

## 3.2 Stormwater BMPs

A site visit was conducted in November, 2006 to investigate and verify problems areas in the watershed and to refine specific BMP recommendations. The site visit accomplished the following:

- Map and prioritize locations of erosion problems along Partridge Lake Road;
- Map and prioritize severity of drainage ditches along Partridge Lake Road;
- Map and prioritize severity of shoreline bank erosion sites along South Shore Road; and
- Shoreline survey to examine areas of beach erosion along Partridge Lake shoreline.

To control stormwater and prevent it from further affecting Partridge Lake, several Best Management Practices (BMPs) were evaluated and considered. BMPs are policies, practices, procedures, or structures that help to prevent environmental damage and are developed specifically to address a particular source of pollution. Both structural BMPs and non-structural BMPs may be utilized to achieve reduction in phosphorus loadings to Partridge Lake. Examples of structural BMPs include detention ponds, stormwater wetlands, infiltration trenches, filtering systems, and conversion of individual septic systems to a community or regional wastewater treatment system. Non-structural BMPs include street cleaning, land use regulations, zoning, and future development restrictions.

*Recommendation: Select appropriate and feasible BMPs for implementation around the lake that will decrease stormwater volume and sediment load.*

Specific recommendations for BMPs to address stormwater runoff in the Partridge Lake watershed are presented below. The Partridge Lake Watershed Partnership will be responsible for further evaluation and selection of the most feasible BMPs to implement.

The evaluation of stormwater BMPs was focused on those structural measures that remove phosphorus as an excess of this pollutant is the primary cause of eutrophication of Partridge Lake. Stormwater BMPs that have been proven effective in removing phosphorus (at least 40% removal rate) are generally biologically oriented such as detention pond and wetland systems which allow for settling of solids and biological uptake of pollutants or infiltration and filtering systems that filter the pollutant out of the stormwater. Challenges to the effective treatment of phosphorus in stormwater at Partridge Lake include the lack of undeveloped public land, unclear road right-of-way and easement boundaries, steep topography adjacent to Partridge Lake, highly permeable soils, and the cold climate. In order to consider a BMP for implementation, its effectiveness for removing phosphorus had to be documented in the literature and not be based solely on manufacturer reported information.

Stream turbidity values, measured in 2000-2001 from tributaries to Partridge Lake, suggest that the estimated TP loading through surface water may primarily be in dissolved form. (See Section 4.2.3 in DES, 2007.) This is important to consider when selecting an appropriate stormwater BMP.

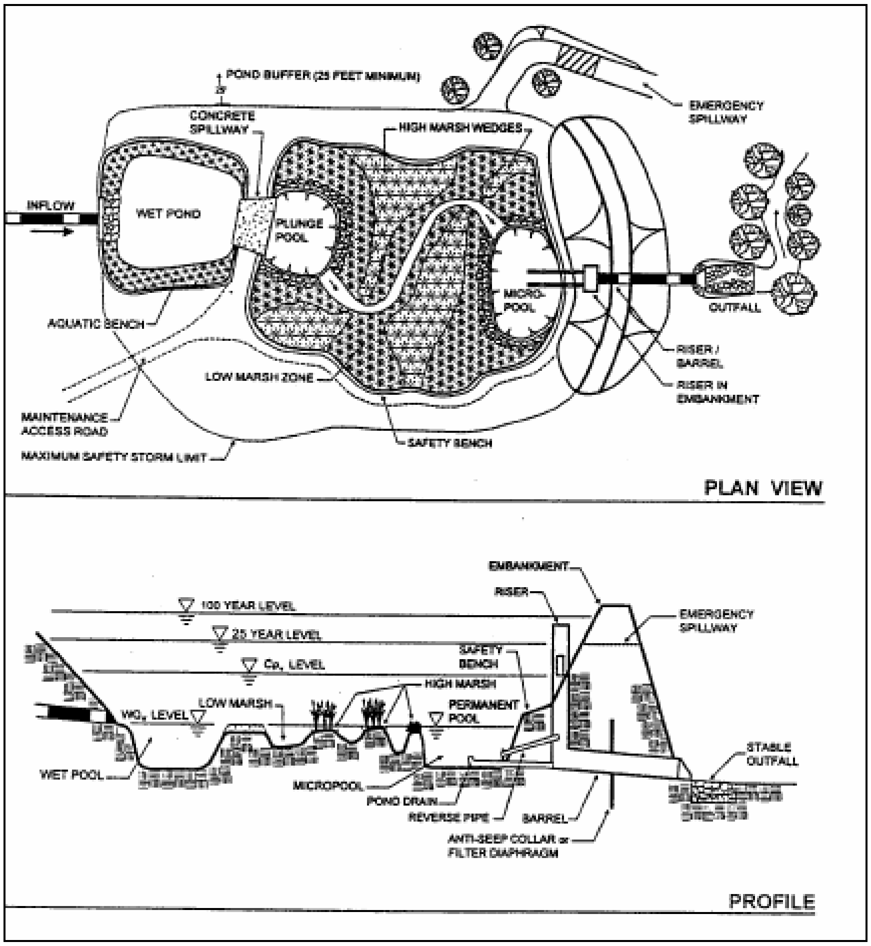
### *3.2.1 Tributary BMPs*

The stormwater BMP concepts considered for implementation for Tributaries A, D, G, and J (detailed below) are a stormwater wetland and several innovative proprietary stormwater systems such as StormTreat, StormFilter, and Aqua-Filter. A description of these concepts follows. The specific location of any potential BMP associated with these tributaries must be permitted by the NH DES Wetlands Bureau.

#### 3.2.1.1 Stormwater Wetland

Stormwater wetlands (a.k.a. constructed wetlands) are engineered systems designed to simulate the water quality improvement functions of natural wetlands to treat and contain surface water runoff pollutants and decrease loadings to surface waters. As stormwater runoff flows through the wetland, pollutant removal is achieved by settling and biological uptake. Wetlands are among the most effective stormwater practices in terms of pollutant removal, and also offer aesthetic value. While natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff, and typically have less biodiversity than natural wetlands both in terms of plant and animal life. There are several design variations of the stormwater wetland, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland. A schematic of an example stormwater wetland is show below.

**Figure 3-1: Schematic of a Stormwater Wetland.**




Source: Center for Watershed Protection.

### 3.2.1.2 StormTreat™

The system consists of a series of six sedimentation chambers and a constructed wetland which are contained within a modular 9.5-foot diameter tank. It is constructed of recycled polyethylene that connects directly to existing drainage structures. Influent is piped into the sedimentation chambers where larger-diameter solids are removed. The internal sedimentation chambers contain a series of skimmers that selectively decant the upper portions of the storm water in the sedimentation basins, leaving behind the more turbid lower waters. The skimmers significantly increase the separation of solids compared with conventional settling/detention basins. An inverted elbow trap serves to collect floatable materials such as oils within the inner tank. After moving through the internal chambers, the partially treated storm water passes into the surrounding constructed wetland through a series of slotted PVC pipes.

The wetland is comprised of a gravel substrate planted with bulrushes and other wetland plants. Unlike most wetlands constructed for stormwater treatment; StormTreat conveys stormwater into the subsurface of the wetland and through the root zone, where greater pollutant attenuation occurs through such processes as filtration, adsorption, and biochemical reactions. The operation and maintenance of the StormTreat System is limited to annual inspections and solids removal on an as-needed basis.

**Figure 3-2: Example StormTreat System Installation.**

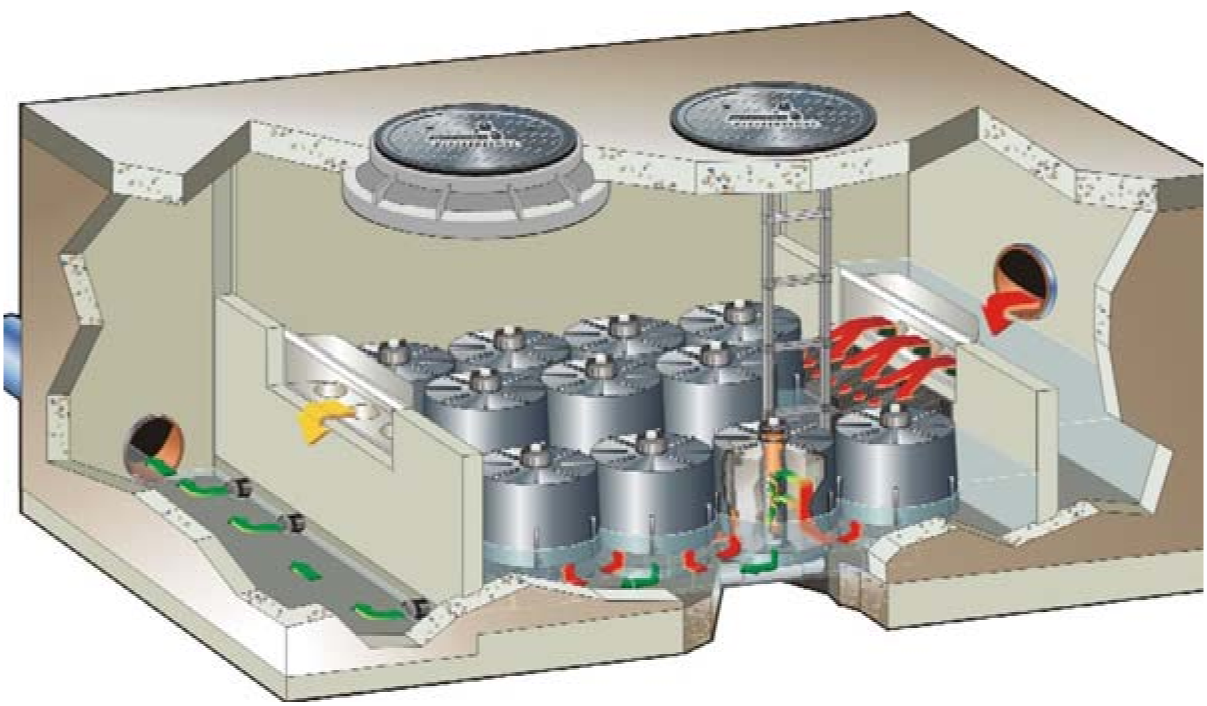

Source: [http://www.stormtreat.com](http://www.stormtreat.com)

### 3.2.1.3 StormFilter

The StormFilter is a passive, flow-through, storm water filtration system that uses rechargeable, media-filled filter cartridges housed in underground concrete vaults. The siphon-actuated cartridges, which draw stormwater through the filter media, are installed in precast or cast-in-place concrete vaults with pipe underdrains cast into the concrete floor. Through mechanical filtration, ion exchange, and adsorption, the filter media removes total suspended solids (TSS), soluble metals, soluble phosphorus, nitrates, and oil and grease from storm water. Filter media for the cartridges are selected based on the pollutants expected at the site. The StormFilter has the flexibility to be fine-tuned with different media if actual pollutant loadings/concentrations at a site differ from expectations, vary with a change in land use, or change due to regulations. Based on the reported conditions for the Partridge Lake sub-watersheds, the manufacturer's initial recommendation is to specify ZPG (zeolite, perlite, and granular activated carbon) for the filter media to remove phosphorus.

Inspection/minor maintenance activities are combined since minor maintenance does not require special equipment and typically little or no materials are in need of disposal. Inspection/minor maintenance typically involves inspection of the vault itself and removal of vegetation, trash, and debris. Major maintenance typically includes cartridge replacement and sediment removal. Inspections and maintenance should be performed annually and after major storms.

**Figure 3-3: StormFilter Schematic.**



Source: http://www.contech-cpi.com

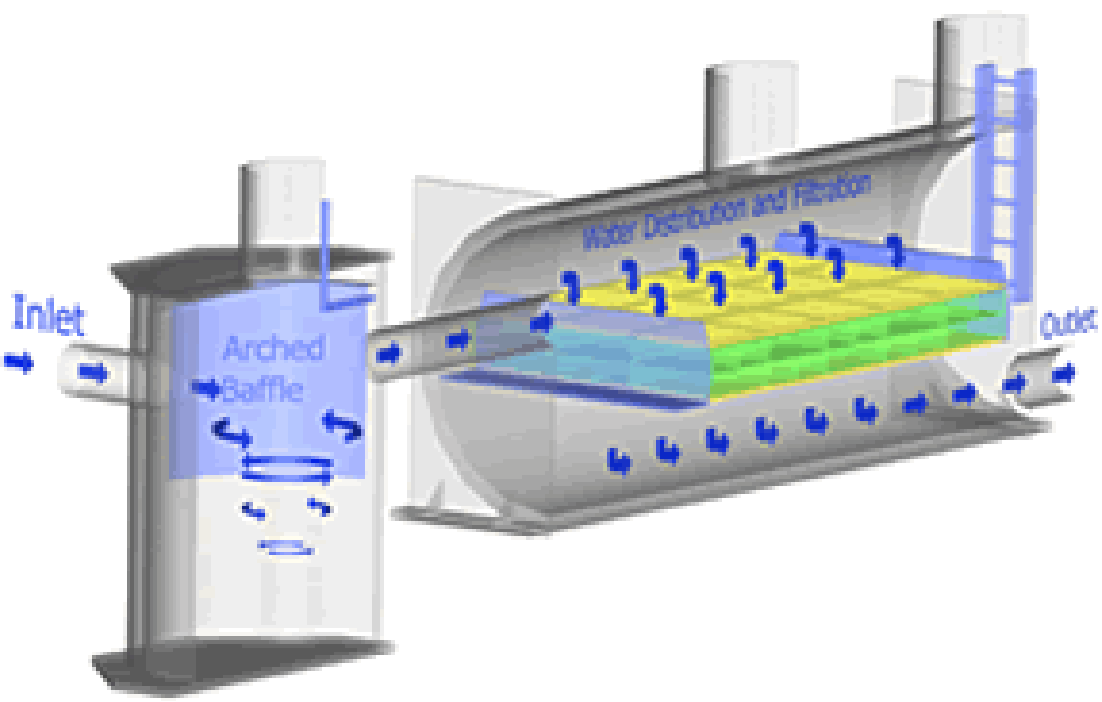
### 3.2.1.4 Aqua-Filter Stormwater Filtration System

Aqua-Filter is a two stage treatment system that involves the removal of gross pollutants by the Swirl Concentrator, followed by the removal of fine sediments and water-borne pollutants by the Filtration Chamber.

Stormwater enters the Swirl Concentrator by means of a tangential inlet pipe that induces a circular flow pattern. The swirling action encourages solids to drop out of the flow and move to the center of the chamber, thereby preventing re-suspension (even under high flow conditions). A baffle plate located in front of the outlet to the Swirl Concentrator traps free-floating oil and debris. The pre-treated "first flush" then enters into the filtration chamber where it is evenly distributed across the filter media bed and allowed to permeate through the filter media.

The natural filter media, used for the filtration, are capable of removing the remaining water-borne pollutants such as dissolved oils, fine silts and clays, nutrients (phosphates), and heavy metals. The most commonly used media is medium grain perlite. Other filter media, such as zeolite, granulated activated carbon and synthetic textiles are available.

**Figure 3-4: Aqua-Filter Schematic.**




Source: [http://www.aquashieldinc.com/](http://www.aquashieldinc.com/)

Table 3-1 provides a comparative assessment of stormwater BMPs considered for phosphorus removal. Specific details on these types of stormwater treatment devices are provided in Appendix 2.

**Table 3-1: Comparison of Stormwater BMPs Considered for Phosphorus Removal.**

| BMP | Phosphorus Removal Rate | Longevity | Applicability | Maintenance |
|---|---|---|---|---|
| Stormwater Wetland | 40% | 20+ years | Requires large amount of land and careful design and planning for wetland plant survival and growth. | Annual inspection of structures and semi-annual inspection of wetland plans and to remove invasive plants. |
| StormTreat | 90% | 20+ years | Applicable to most sites. | Minimal maintenance- annual inspection & cleaning, sediment pumped every 3 years on average |
| StormFilter | 40% | 20+ years | Applicable to most sites. | Annual maintenance for sediment removal and cartridge removal and recharging |
| Aqua-Filter | 90% | 20+ years | Applicable to most sites: small unit area (0.5 cfs) - 14' long x 7' wide larger unit area (1.0 cfs) - 16' long x 8' wide | Annual inspection & sediment removal and filter replacement every 12-18 months |

3.2.1.5 Design Conditions

Implementation of stormwater BMPs focused on the four tributaries with the highest phosphorus loadings to Partridge Lake – Tributaries A, D, G, and J - as measures to reduce phosphorus loadings in these tributaries will have a more pronounced effect. The smaller tributaries were not included in the design conditions analysis; however, phosphorus loads for all tributaries and cost estimates for generic BMPs for the smaller tributaries (those not mentioned in this section) are provided in later sections of this Plan for comparison.

The base criterion developed for BMP sizing varies by locale and whether the BMP is for new construction or a retrofit. Since approximately 90% of precipitation events are one inch or less often the base criterion for water quality treatment volume is the one inch rainfall event. For new development projects, the design criterion is the 2-year, 24-hour storm. This magnitude storm is larger than approximately 98% of the precipitation events. An analysis of precipitation records for the period 1978 to 1994 of the Concord, New Hampshire Weather Service Observatory showed that about one half of the events were less than 0.3 inches in rainfall and about one-half the rainfall volume were produced by events of one inch or less (1996). Since design sizing criteria may vary, the design flows and volumes were calculated for the one inch, 24-hour storm and the 2-year, 24-hour storm for selected tributaries.

As part of the conceptual BMP design for these four tributaries, the computer program, TR-20 was used to determine stormwater runoff rates and volumes for different design storms. The SCS Unit Hydrograph Methodology was used to model different storm events. The tributary sub-basins were delineated by DES. Curve numbers (CN) were calculated based on soil type and existing land use for each tributary sub-basin. Time of concentration (Tc) was calculated for the four tributaries using the velocity method. Tc and CN calculations can be found in Appendix 3. Rainfall hydrographs were developed using the Soil Conservation Service (SCS) Type II rainfall distribution. Two different storm events were modeled – the 1 inch, 24-hour storm and the 2-year, 24-hour storm of 2.0 inches (NRCC 1993). Table 3-2 lists the peak flow and runoff volume for these two storms for the four tributaries.

**Table 3-2: Peak Flow and Runoff Volumes for Selected Tributaries to Partridge Lake.**

| **Tributary** | **Peak Flow** | | **Run-off Volume** | |
|---|---|---|---|---|
| | 1” 24-hour storm | 2-yr 24-hour storm | 1” 24-hour storm | 2-yr 24-hour storm |
| A | 0.07 cfs | 7.9 cfs | 0.041 Ac-ft | 1.95 Ac-ft |
| D | <0.01 cfs | 2.7 cfs | - | 1.40 Ac-ft |
| G | <0.01 cfs | 1.3 cfs | - | 0.59 Ac-ft |
| J | 0.06 cfs | 10.9 cfs | 0.021 Ac-ft | 2.31 Ac-ft |

Note: Run-off volumes for Tributaries D and G were too low to accurately quantify.

Tributaries A, D, G, and J have the highest loading partly because three of them are year-round tributaries with the large drainage areas and some of them also have agricultural activities which may contribute higher phosphorus loadings than the predominant forested or residential land uses. The drainage areas for tributaries A, D, G, and J are 97, 164, 69, and 128 acres, respectively.

The BMPs were sized to accommodate the 1-inch, 24-hour storm because the design for the 2-year, 24-hour storm would be cost-prohibitive and likely unfeasible due to land constraints. Table 3-3 lists the capital, installation, and annual maintenance costs for each of the BMP design concepts for the four sub-watersheds. Specific areas for stormwater BMPs are discussed below in the order of phosphorus loading.

**Table 3-3: Comparative Costs of Selected BMPs for Partridge Lake Subwatersheds.**

| BMP | Capital Cost | Installation Cost | Subtotal (Capital plus Installation) | Maintenance Cost |
|---|---|---|---|---|
| **Subwatershed J – 3.9 kg P annually** | | | | |
| Stormwater Wetland | - | $245,000 | $245,000 | $5,000 |
| StormTreat | $35,000 | $5,000 | $40,000 | $2,000 |
| StormFilter | $15,000 | $3,750 | $18,750 | $1,000 |
| Aqua-Filter | $32,000 | $8,000 | $40,000 | $1,100 |
| **Subwatershed D – 3.2 kg P annually** | | | | |
| Stormwater Wetland | - | - | - | - |
| StormTreat | $7,000 | $1,000 | $8,000 | $400 |
| StormFilter | $15,000 | $3,750 | $18,750 | $1,000 |
| Aqua-Filter | $27,000 | $6,750 | $33,750 | $850 |
| **Subwatershed G – 2.9 kg P annually** | | | | |
| Stormwater Wetland | - | $145,000 | $145,000 | $2,900 |
| StormTreat | $7,000 | $1,000 | $8,000 | $400 |
| StormFilter | $15,000 | $3,750 | $18,750 | $1,000 |
| Aqua-Filter | $27,000 | $6,750 | $33,750 | $850 |
| **Subwatershed A – 2.6 kg P annually** | | | | |
| Stormwater Wetland | - | $190,000 | $190,000 | $3,800 |
| StormTreat | $70,000 | $10,000 | $80,000 | $4,000 |
| StormFilter | $15,000 | $3,750 | $18,750 | $1,000 |
| Aqua-Filter | $32,000 | $8,000 | $40,000 | $1,100 |

Maintenance costs are estimates based on discussions with the manufacturers. The differences in StormTreat costs per watershed are based on run-off volume, as higher volumes would require running a series of StormTreat devices.

### *3.2.2 Selected Subwatersheds/Tributaries*

#### 3.2.2.1 Tributary J

Tributary J drains a forested section of the watershed north of the lake (Figure 3.5). The lower portion of the stream runs through residential areas and crosses under Partridge Lake Road before entering Partridge Lake. Phosphorus loading from this subwatershed from June 2000 through May 2001 was calculated to be 3.9 kg/yr.

The subwatershed is largely forested, with the majority of the residential development right along the shore. According to Table 3-3 the most cost effective solution to decrease phosphorus in stormwater runoff is either to install a StormTreat or Aqua-Filter system on the upstream side of Old Partridge Lake Road. Other BMPs that were evaluated for this location included a stormwater wetland which was cost prohibitive.


*Photo: Tributary J running along Partridge Lake Road.*

#### 3.2.2.2 Tributary D

Tributary D subwatershed is almost completely forested, with a small area of old dairy farmland in the upper part of the watershed (Figure 3.6). Hubbards Road contains several culverts passing runoff and flow. Phosphorus loading from the subwatershed draining Tributary D from June 2000 through May 2001 was calculated to be 3.2 kg/yr.

Since Tributary D is an intermittent stream, the Aqua-Filter system is recommended for stormwater treatment because it doesn't require a reliable source of water and provides a good phosphorus removal rate. Neither the StormTreat nor the stormwater wetland is feasible as they require a more stable source of water.

#### 3.2.2.3 Tributary G

Phosphorus loading from the subwatershed draining Tributary G from June 2000 through May 2001 was calculated to be 2.9 kg/yr. The watershed area is primarily forested, although a portion of the watershed consists of an old dairy farm in Lyman (Figure 3.7). At this location, the StormTreat system is the least costly BMP and has a high phosphorus removal rate. Given that the dairy farm is no longer in operation, phosphorus sampling of Tributary G should be conducted and the results compared with data collected in 2000/2001 for the DES diagnostic study. This would give an indication of the source and severity of the phosphorus loading through Tributary D without active agricultural land use in this subwatershed.

If re-sampling indicates a persisting phosphorus problem in Tributary G, then a combination of BMPs may work best at this site including the StormTreat system, road sand clean-up, and potentially the wetland areas along Hubbard Road may be treated with alum to neutralize the historical phosphorus loading in the wetland areas of the subwatershed from the dairy operations.

3.2.2.4 <u>Tributary A</u>

The annual phosphorus loading to Partridge Lake from Subwatershed A is 2.6 kg/yr, based on the measurements collected from June 2000 through May 2001. Tributary A flows primarily through forested areas and adjacent pasture where horses have access to the stream for drinking, etc. The lower portion of the creek flows through a steep-sloped residential area along Old Partridge Lake Road, crosses through a culvert under Partridge Lake Road and into the lake (Figure 3.8). Old Partridge Lake Road experiences high stormwater runoff rates during storm events which carry sand and road pollutants into the lake adjacent to Tributary A. A potential solution to reduce phosphorus loadings could be a sediment trap/treatment device at the base of Old Partridge Lake Road. The cost for the Aqua-Filter system and StormFilter are approximately half that of the StormTreat system. The Aqua-Filter system is recommended although it has a higher cost than the StormFilter system because its phosphorus removal rate is twice that of the StormFilter system. A stormwater wetland is not feasible due to the limited amount of available land, high cost, and lower phosphorus removal rate. In addition to the predicted phosphorus removal rates of the recommended BMPs, the high visibility of this site may warrant any improvements considered here as high priority.

Another essential component at this location is maintenance, either in the form of clean-up along existing roads during the spring and maintenance of any BMP that may be installed for runoff and sediment control. Town participation is essential.

*Photo: Run-off over Partridge Lake Road entering Tributary A.*

*Photo: Sediment deposited on Old Partridge Lake Road after storm.*

**Figure 3-5: Subwatershed J.**

Attached as .pdf

**Figure 3-6: Subwatershed D.**

Attached as .pdf

**Figure 3-7: Subwatershed G.**

Attached as .pdf

**Figure 3-8: Subwatershed A.**

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### *3.2.3 Road BMPs*

#### 3.2.3.1 Ditching and Road Diversions

Another component to reducing sediment to the lake is the periodic maintenance of roadside ditches. In general, ditches or roadside swales are supposed to convey water and don't provide much treatment for phosphorus removal. This seems especially true at Partridge Lake where soil percolation rates are high and the groundwater table is presumably near the surface in the vicinity of the lake.

During the field visit in November 2006, several ditches along Partridge Lake Road that could use improvement were documented (Figure 3-9). There are at least 850 linear feet of ditch that could be excavated and filled with course stone or rip-rap to promote the containment of sediment particles present in stormwater runoff. Although, if the ditches shown in Figure 3.9 were improved, road run-off from the entire length of Partridge Lake Road from the junction of Old Partridge Lake road, west for approximately 3,500 feet would be captured. It is recommended that the PLPOA and Town of Littleton work together to examine potential for ditch improvements around the lake. The Littleton town highway department which has been very receptive to these ideas has expressed interest in working on solutions to these issues. Close contact and cooperation with the town highway department is essential in developing a plan for improving the ditches, culverts and roads around the Lake, as well as the required maintenance involved.

Road diversions were effectively implemented at a 319 Project in Maine recently at Echo Lake, which was facing similar phosphorus and runoff problems as Partridge Lake. The goal of that project was to reduce sediment and phosphorus loading in the lake through installation of armored culverts and ditch work along the lakeside roads (Kennebec County SWCD, 2006).

With proper turnouts and buffers, ditches keep pollution from reaching sensitive water resources. Water should be routed away from the road and turned out frequently, if possible, so that it can be discharged into a stable vegetated area a little at a time. This practice allows the water to filter and absorb into the surrounding vegetation and prevents large volumes of water from accumulating in the ditch (Kennebec County SWCD, 2006). Challenges to this approach around Partridge Lake include a lack of available land adjacent to the lake and the steep topography along shore roads.

There are many impediments to implementing an effective road ditch improvement strategy along Partridge Lake Road. First, while stone-lined ditches may trap sediment on a short-term basis, they have not been proven effective at phosphorus removal. Secondly, Partridge Lake Road is very narrow with limited shoulders available for ditch improvements. This factor alone may prevent the effectiveness of ditch improvements in this area. Finally, while installing a series of turn-outs along the ditch line theoretically would reduce the volume of stormwater and sediment traveling along the road, the topography and land use surrounding the road would provide only limited opportunity for this practice. For example, all of the ditching opportunities are present on the north side (landward) of Partridge Lake Road, which has very steep topography. There are only limited areas where diverting stormwater away from this side of the road would not make flooding worse due to the steep topography. The south side of the road contains residential development prohibiting the placement of ditch turnouts. For these reasons, the improvement of the ditches along this road is not the recommended option. It would be more feasible and effective if the above mentioned proprietary stormwater devices are installed along the road for phosphorus reduction.

### 3.2.3.2 Road Sanding Collection and Clean-Up

*Recommendation: Design and implement an intensive road maintenance (street sweeping) schedule for the roads in the Partridge Lake watershed.*

In spring, road surfaces warm and snow and ice melts. Accumulated winter traction materials loosen and dry, and their fine fraction can be entrained by stormwater runoff. In addition to increasing turbidity and depositional loading, the sediment from sanding operations can retain and transport other pollutants to the receiving waters and thus impair water quality (Smith, 2002). Because of this, spring cleaning of accumulated winter traction materials is an essential part of mitigating phosphorus content of stormwater runoff. In fact, seventy percent of cold climate stormwater experts recommend street sweeping during the spring snowmelt as a pollution prevention measure (Caraco and Claytor, 1997).

Regular street sweeping helps to prevent deposition of sediment into surface waters by wash-off. Currently the town provides street sweeping around Partridge Lake in the spring once per year with a vacuum assisted wet sweeper and a bucket sweeper. PLPOA members have suggested that real-time management, based not on a fixed frequency or schedule, but rather on the degree of accumulation and on rainfall forecasts, may be effective at minimizing the sediment available for wash-off during a precipitation event. The town may not have enough manpower to provide real-time management; however, the town highway department has been very receptive to these ideas and has expressed interest in working with lake residents on solutions to these issues. Trouble spots for road sand accumulation in the Partridge Lake watershed include the paved roads, which include most of Partridge Lake Road and Old Partridge Lake Road. See photo below.

Another potential BMP is to upgrade the street sweepers used by the town to a high-tech regenerative air street sweeper which is capable of removing finer sediment (that phosphorus more readily adheres to) than the street sweepers the town currently uses.

*Photo: Road sand accumulation along Partridge Lake Road.*

**Figure 3-9: Potential Ditch Improvement Areas Along Partridge Lake Road.**

Attached as .pdf

### 3.2.4 Shoreline BMPs

#### 3.2.4.1 South Shore Road

The steep hillside shouldering the road on the south side and near absence of any shoulder on the north (shore) side is compounding the NPS problem. This may be an area where riparian buffer restoration or shoreline stabilization will help keep sediment and nutrients out of the lake. The shoreline is generally well vegetated however. No town maintenance is provided on South Shore Road as it is a private road. Any improvement to this road or the associated shore line could not be performed by the town. However, ground cover or small shrubs could be planted by the Lake Association or property owners in some of the unvegetated areas along South Shore Road to reduce erosion and capture road sediment and sand. Reducing the amount of suspended solids that runoff to the lake will likely improve particulate phosphorus loadings.

The ability of riparian buffers to trap suspended solids is positively correlated with width and negatively correlated with slope. The minimum recommended width of a filter strip should be 75 feet and slope should not exceed 15% (DES, 1996a). Given the limited availability of shore front property for conversion into buffer, and the relative steepness of the banks, the efficiency of this remedial measure may not be great.


*Photo: South Shore Road.*

### 3.2.4.2 Beach Erosion

*Recommendation: Encourage PLPOA to improve beaches to prevent erosion.*

There is a general perception in the community that adding sand to a beach is not good for water quality and therefore many beach owners do not replenish sand on their beaches. Lakefront property owners should, however, be encouraged to examine the construction of their beaches. As recommended in the DES Report, beaches should be re-vamped so that they are perched or so that slopes are minimized to lessen the impacts of overland runoff and subsequent erosion. This will require landowner cooperation and permitting through DES Wetlands Bureau.


Typical beach configurations as shown in the photo taken along Partridge Lake Road (right), usually begin at the edge of the road, are steeply sloped, and meet the waters edge. By installing a permitted perched beach with a diversion trench along the upper limit of sand, overland runoff is diverted around a sloping beach, and rocks placed at the toe of the slope prevent direct washing of the sand to the lake (DES, 2007). The DES Wetlands Bureau has guidelines for establishing perched beaches to reduce the likelihood of erosion and sedimentation. The Wetlands Bureau not only requires permits for beach construction and replenishment, but also restricts the time interval between beach replenishments to once every 6 years and in general may not exceed more than 10 cubic yards of sand.

Beach improvement by landowners may be encouraged through outreach and educational materials, such as the Lake Guide developed by PLPOA. Incentives to improve beaches may include help with labor from the PLPOA and/or the town during the Phase 1 road improvements.

## 3.3 Land Use, Protection, and Conservation

*Recommendation: Work with town and residents to consider developing a Zoning Overlay Protection. Hire a Watershed Coordinator to assist in researching zoning updates, examining build-out scenarios in the watershed, and implementing other recommendations in this plan.*

Currently, there are state and local rules in effect to restrict development around surface waters. The state-wide Comprehensive Shoreland Protection Act (CSPA) establishes guidelines for activities taking place within 250 feet of the high water line of the lake, commonly called the "protected shoreland." Within the protected shoreland, certain activities are restricted or prohibited, and others require a permit from the DES. Some of restrictions of the CSPA relevant to protecting Partridge Lake water quality include: setback requirements for all new septic systems are determined by soil characteristics, maintaining natural woodland buffers, minimum lot sizes, and minimum setback distances of structures from the water line.

The Town of Littleton currently has included a minimum septic system setback requirement of 125 feet from the shoreline of a waterbody in their town zoning ordinances, but the ordinances include few other measures to protect lakes and ponds. In addition, the area around Partridge Lake is zoned a rural residential. The minimum lot size for new residential development is two acres.

In the Partridge Lake watershed, new homes were recently developed within the 250 foot Protected Shoreland area. In addition, the town, as well as the lake association, has been approached with proposals for developing larger tracts of land within the watershed of Partridge Lake. Efforts are currently underway to protect land along Hubbards Road south of the lake from development.

A zoning overlay for a Lake Protection Zone through the Town of Littleton to protect areas that are not suitable for development based on soils, proximity to the lake, or other factors should be developed. Local zoning and land use regulations could be revised to prevent sprawling development from occurring throughout the watershed and encourage (or require) more environmentally-friendly site design, including improved on-site stormwater management, for new development. If development occurs near the lake, enforce the use of protective devices including silt fences, hay bales, check dams, and appropriate setbacks

Zoning ordinances and overlay districts should be created or expanded in ways that are consistent with the provisions of the Shoreland Protection Act and with new and innovative Smart Growth and Low Impact Development planning. It is recommended that the Partridge Lake Association and the Town of Littleton designate a subcommittee, or acquire a consultant to act a Watershed Coordinator, to investigate options for developing town and watershed wide zoning overlays and districts that are consistent around the lake. Example plans are provided in DES, 2007 as guidelines for use when formulating appropriate zoning and overlay districts for the watershed area of Partridge Lake.

## 3.4 Agricultural Operations and Pasture Management

*Recommendation: Educate agricultural property owners in the watershed on BMPs applicable to their operation.*

There is a 20 acre plot of land that recently has been used as horse pasture within the Partridge Lake watershed. There is also a former dairy farm in Lyman within the watershed, which has scaled own its operations to currently pasture only 10-12 young cows each summer. These areas represent a very small percent of the total watershed area; however, they could have had an impact on phosphorus loading into the lake if not properly managed. The practices of the pasture operator should be determined and potential improvements to the management of the pasture may be suggested.

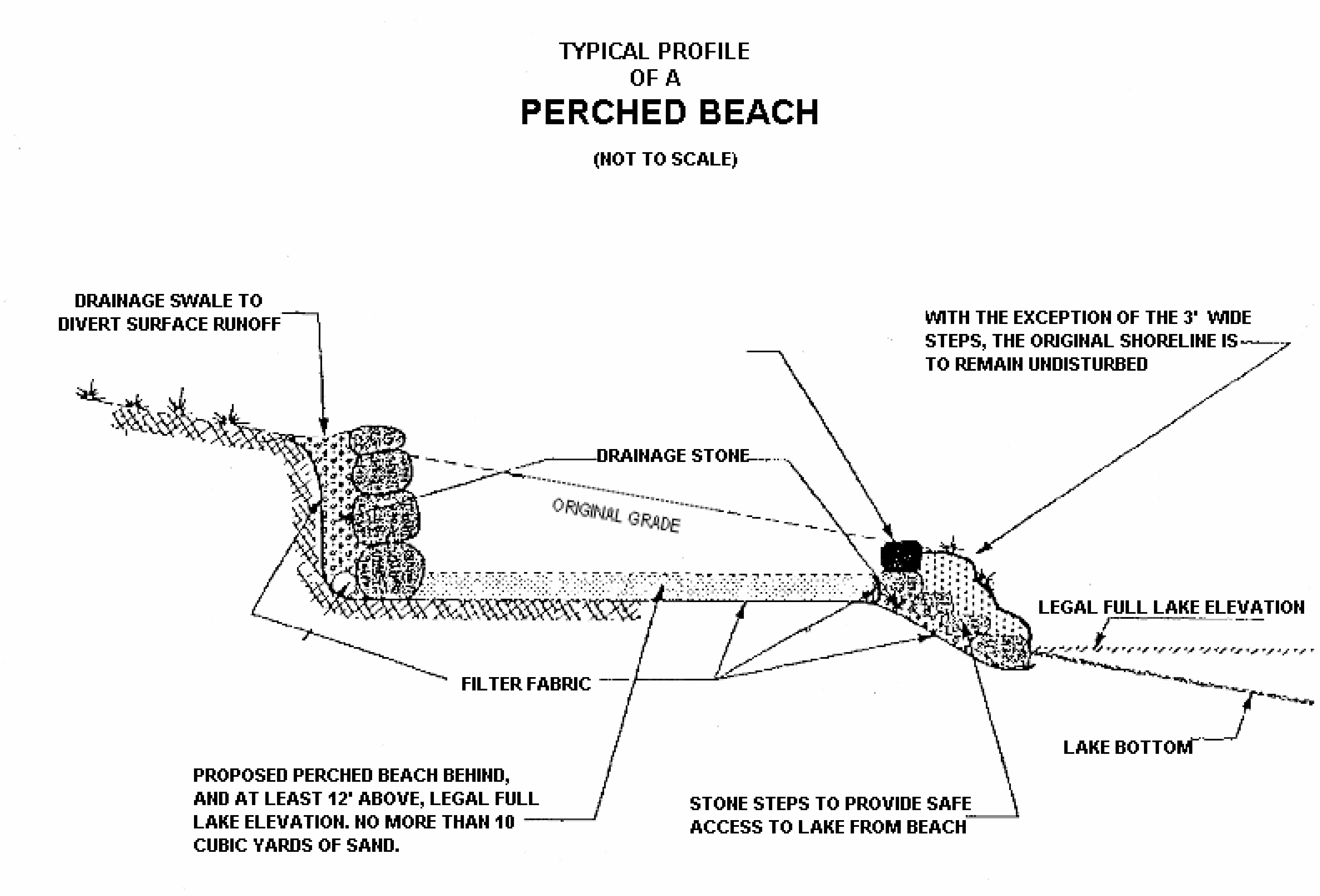
Provide education and outreach to the agricultural community to promote manure management support, and other BMPs, to help meet the water quality standards in Partridge Lake. Actively contact individual farmers to solicit participation. Support can be obtained from the County Cooperative Extension.

In addition to current local zoning and state regulations, potential BMPs may include manure management, stream fencing, and vegetated riparian buffers along affected streams. The goal is to improve water quality protection on and around pasture areas by increasing the understanding of owners about BMPs that can be used on their farms.

**Figure 3-10: Areal Coverage of 2007 Septic Survey.**

Attached as .pdf

**Figure 3-11: Cross Sectional View of a Perched Beach.**




Source: “Protect Your Lake: Beaches and Water Quality,” in DES, 2007.

## 3.5 Residential Practices through Education

*Recommendation: Educate homeowners on steps they can take to reduce nonpoint source pollution. Distribute Lake Guide to watershed residents.*

As part of this Project, a Lake Guide was developed by PLPOA for distribution to watershed residents. The guide provided ideas to limit lake pollution from their home site. Some of the topics addressed include:

- Limiting impervious cover by building a rain garden.
- Stormwater diversions from paved driveways and roadways (water bars) and rain barrels.
- Maintaining permeable areas, forested and ground cover buffers, and keeping lawns and paved areas to a minimum are critical in maintaining the health of the lake.
- Encourage more lake residents to become volunteer Weed Watchers. Long-term records of plant growth (both native and exotic) can be valuable tools in tracking the aging of a lake.

Rain gardens combine shrubs, grasses, and flowering perennials in depressions (about 6 to 18 inches deep) that allow water to pool for only a few days after a rain. They slow stormwater runoff and increase its infiltration into the soil. They can also be incorporated into road shoulder rights-of-way.

Rain barrels, sometimes called cisterns, are aboveground water storage vessels. They capture rain runoff from a building's roof using the gutter and downspout system. They work by diverting water from storm drain systems and thus reducing pollutants and the velocity of water entering local rivers and streams. Locate rain barrels under downspouts where rainwater can be most easily collected for transport away from building foundations into a garden or onto the yard.

## 3.6 Alum Treatments

*Recommendation: Treat Partridge Lake with aluminum salts to neutralize the internal phosphorus loading.*

Even though the estimate of internal phosphorus loading to Partridge Lake is greater that all external sources combined, DES stressed in their findings that external, watershed based phosphorus sources must be addressed through the implementation of appropriate BMPs aimed at decreasing or eliminating pollutants before they enter into Partridge Lake. These pollutant sources must be mitigated before in-lake restoration or rehabilitation techniques, such as in-lake phosphorous inactivation treatments, can be successful. Any in-lake restorative work provided before watershed management is not cost-effective as the pollutant sources will soon create a reoccurrence of similar in-lake problems.

Aluminum sulfate, sodium aluminate and ferric sulfate are effective components of whole lake restoration. Properly and competently applied these materials reduce the bioavailable phosphorus by forming insoluble, inactive precipitates. These precipitates are incorporated into the sediments and prevent recycle of soluble P from sediments to the water column, further preventing eutrophication. This option should be investigated further, with technical support from DES, once the external inputs of phosphorus are reasonably controlled. Cost estimates for treating Partridge Lake are provided in the next section of this plan.

In addition to the in-lake treatment, the feasibility of treating wetland areas, such as those in subwatershed H, and subwatersheds D/B, should be investigated. These two wetland areas may be saturated with phosphorus from historical agricultural loadings in the watershed. Tributary H is located at the southern tip of Partridge Lake. The watershed area is primarily forested, although a portion of the watershed consists of the dairy farm in Lyman. June 2000 through May 2001 TP Loading was 1.2 kg.

## 3.7 Summary of Recommendations

- *Select appropriate and feasible stormwater improvements or structural BMPs for implementation around the lake that will decrease stormwater volume and sediment load. Focus in tributaries with the highest phosphorus loading. Re-sample to determine phosphorus levels in Tributary G.*

- *Design and implement an intensive road maintenance (street sweeping) schedule for the roads in the Partridge Lake watershed.*

- *Pursue improvements to individual septic systems and consider alternatives such as a community system.*

- *Reserve/acquire land areas for potential cluster septic systems for future analysis.*

- *Work with town and residents to consider developing a Zoning Overlay Protection.*

- *Hire a Watershed Coordinator to assist in researching zoning updates, examining build-out scenarios in the watershed, and implementing other recommendations in this plan.*

- *Educate agricultural property owners in the watershed on BMPs applicable to their operation.*

- *Encourage PLPOA to improve beaches to prevent erosion.*

- *Educate homeowners on steps they can take to reduce nonpoint source pollution.*

- *Treat Partridge Lake, and possibly the surrounding wetlands with aluminum salts to neutralize the internal phosphorus loading.*

# 4 ESTIMATED LOAD REDUCTION FROM PLANNED MANAGEMENT MEASURES

The overall objective of the Watershed Based Plan is to implement management measures to increase in-lake water quality such that Partridge Lake is removed for the impaired waterbodies list. That is, reduce phosphorus and sediment loads to levels that are expected to result in attainment of all water quality criteria that support the designated uses for the lake. Specifically, the primary goal is to prevent the eutrophication of Partridge Lake by reducing the phosphorus load. The decreases achieved in phosphorus loading are predicted to reduce excessive algal blooms, and increase oxygen levels in the lake.

As stated in the Water Quality Objectives Section, the targeted reduction of phosphorus from external or watershed sources is 25-30%. In terms of actual loading this would translate into approximately 10.0 kg TP reduction annually, based on annual loading of 39.8 kg from surface and groundwater inputs (minus precipitation). Tributary sources were measured in 2001 as 16.4 kg/year and the groundwater inputs were measured as 23.4 kg/year.

Using the data presented in the DES Study, Partridge Lake with the 70 kg/yr phosphorus internal loading added results in the lake being characterized as borderline eutrophic. Using the Vollenweider relationship, if the internal loading is removed, the resulting lake trophic status is mesotrophic. Prior to implementing any mitigation measures to neutralize the internal loading, external sources must be reasonably controlled to the greatest extent feasible, targeted at 25-30%. Otherwise, any internal loading mitigation would prove ineffective.

Since both the Dillon/Rigler and Vollenweider models show that the lake is transitioning between oligotrophic and mesotrophic trophic classifications, additional loading to Partridge Lake would likely push the lake further into more advanced mesotrophic or eutrophic classifications.

These trophic calculations can be used to determine a reasonable reduction target for phosphorus into Partridge Lake. To achieve the targeted load reductions, the various loadings will be examined from a source perspective. That is, each source will be examined for potential reductions based upon different methods and then the pieces will be assembled to predict achievable load reductions. Estimated phosphorus load reductions were estimated using various methods as detailed below.

## 4.1 <u>Groundwater</u>

There have been relatively few attempts at developing modeling tools to predict and simulate nutrient fate and transport mechanisms from septic system effluent (EPA, 2002b). Conventional septic systems remove only 15 to 30 percent of the phosphorus in raw wastewater. Phosphorus loading problems might be encountered in areas with older systems, highly permeable soils (e.g., sands), mineral-poor soils, nearby surface waters, and high system densities (EPA, 2002b). There is also the potential that surrounding soils may become saturated with nutrients. Over time the capacity of soils to attenuate septic system phosphate can be consumed, allowing phosphate to advance at a slow but potentially significant rate (Harman et al., 1996).

Background concentrations of phosphorus in groundwater are typically less than 0.01 mg/L or 10 ppb (McCobb et al, 2003). Groundwater monitoring programs in New Hampshire, such as those conducted by the Department of Agriculture and DES do not normally sample for phosphorus (B. Wolff, NH Dept. of Agriculture, and R. Chormann, DES, pers. comm.).

Using the demographic data provided by the PLPOA, the results of the 2007 septic survey, and generalized characteristics of septic system effluent, the theoretical phosphorus loading to groundwater for lakeside homes was calculated using the mass loading equation. There are approximately 68 dwellings in the immediate vicinity of the lake's edge. Nineteen of these properties are considered to be year-round dwellings (only 16 were within 300 feet), and the remaining 49 are seasonal, all within 300 feet of the lake. It was assumed that an average of 2.3 people reside in each home, and year round homes were occupied for 351 days per year (365 minus two weeks for vacation), and seasonal homes were occupied for 60 days per year.

From Metcalf and Eddy 1979, the following assumptions were made:

- Typical wastewater flow from residential source is 380 L/person/day.

- Actual quantities of constituents in wastewater will vary widely. However, for the purposes of estimating loading and load reductions, typical concentrations found in Metcalf and Eddy 1979 were used. Municipal wastewaters may contain from 4 to 15 mg/L of phosphorus as P. EPA also reports that concentrations of TP in typical residential wastewater range from 6-12 mg/L. For this analysis, the value of 8 mg/L was used.

- A mass loading calculation was used to determine phosphorus loading:

  *Mass loading, kg/day = (concentration, mg/L)*(Flow rate, L/d)/$10^6$ mg/kg*

Using these values and assumptions, each person provides approximately 0.003 kg of total phosphorus/day in effluent, equivalent to 1.1 kg/year. For both year-round and seasonal residents, the amount of phosphorus entering septic systems around Partridge Lake was calculated to be 60.6 kg/year. This calculation does not account for the efficiency of phosphorus removal in septic systems. The 2007 septic results also provided more detail on septic system usage around the lake. Regardless of the management measure proposed (individual improvements, group maintenance, cluster system), this per capita estimate of phosphorus loading can be used to determine estimated load reduction from potential septic system management measures.

For example, if all 16 of the year round lake homes within 300 feet of the lake were converted to a community system located away from the lake, the estimated reduction in phosphorus loading to groundwater (assuming 50% removal efficiency) would be approximately 20 kg/year or 88 % of the groundwater phosphorus loading to the lake.

In contrast, if seasonal lake home owners were to implement individual septic system improvements (roughly assuming the combined removal efficiency of 50%), for each system an annual load reduction of 0.20 kg of total phosphorus is estimated for each system improved. These improvements may not figure to be the most cost effective; however, a targeted approach may be useful in identifying areas of high phosphorus loading based on the complete septic system survey (Appendix 1). As an example, 20 of the survey respondents indicated that their system was less than or equal to 100 feet from the lakeshore. Of these, seven are year-round homes and the remainder are seasonal. Using the occupancy data provided by the respondents, the estimated phosphorus production of this group is 27.5 kg/year. Improving this target group of septic systems would achieve a 13.7 kg/year phosphorus reduction.

Even though septic pumping frequency at Partridge Lake is within DES recommendations, more frequent pumping may be beneficial in certain areas around the lake. The group maintenance scenario, which may be the quickest to implement given cooperation of PLPOA, could substantially decrease phosphorus loading to groundwater depending on participation. Further, the social changes that may result from the septic system education program (through lake guide dissemination) described later may improve the situation.

Certain locations around the lake may be prime areas in terms of a community system or an aggressive group maintenance schedule. Using the results from the septic survey again as an example, the 20 respondents indicating that their system was less than or equal to 100 feet from the lakeshore were generally located in two clustered areas as shown in Table 4-1 (assuming the removal efficiency of 50%). Addressing these clustered areas may lead to an annual phosphorus reduction of 4.40 - 9.34 kg or 0.55 – 0.78 kg/household.

**Table 4-1: Phosphorus Load Reduction Estimates for Clustered Septic System Improvements.**

| Cluster | Subwatersheds | Systems within 100 feet | Annual Phosphorus Load (kg) | Estimated Load Reduction (kg) | Reduction per Household (kg) |
|---|---|---|---|---|---|
| 1 (north-west) | P11, K, I, P5 | 12 | 18.7 | 9.34 | 0.78 |
| 2 (south-east) | G, F, P13, B | 8 | 8.8 | 4.40 | 0.55 |

Note: See Figure 3-10 for subwatershed and respondent locations.

## 4.2 Stormwater BMPs

### *4.2.1 Stormwater Retrofits*

Estimated load reductions for individual tributary BMPs were calculated based on documentation in the literature. Although the phosphorus removal rates for StormTreat and Aqua-Filter, the recommended treatment options, are reported to be 90% or higher, a lower removal rate of 80% was assumed for load reduction calculations. Table 4-2 presents the estimated phosphorus reductions of the proprietary stormwater treatment devices recommended for each subwatershed.

**Table 4-2: Phosphorus Load Reduction Estimates for Stormwater Treatment Devices.**

| BMP Description | Subwatershed | BMP Efficiency | Annual Phosphorus Load (kg) | Estimated Load Reduction (kg) |
|---|---|---|---|---|
| StormTreat or Aqua-Filter | J | 0.8 | 3.9 | 3.12 |
| Aqua-Filter | D | 0.8 | 3.2 | 2.56 |
| StormTreat | G | 0.8 | 2.9 | 2.32 |
| Aqua-Filter | A | 0.8 | 2.6 | 2.08 |

The combination of stormwater BMPs proposed above will result in an estimated reduction of 10.08 kg of phosphorus per year. If there is a need to install similar BMPs in the smaller subwatersheds of Partridge Lake, Table 4-3 provides an estimate of the respective load reduction of this management measure. It should be noted that the effectiveness and sizing requirements of installing the proprietary BMPs in these smaller subwatersheds were not analyzed. Table 4-3 is provided simply for comparison purposes.

**Table 4-3: Phosphorus Load Reduction Estimates for Smaller Subwatersheds.**

| Subwatershed | Annual Phosphorus Load (kg) | Percent of Total Subwatershed Sources | Theoretical BMP Efficiency | Estimated Load Reduction (kg) |
|---|---|---|---|---|
| B | 0.12 | 1% | 0.8 | 0.08 |
| E | 0.94 | 5% | 0.8 | 0.72 |
| F | 0.36 | 2% | 0.8 | 0.32 |
| H | 1.17 | 7% | 0.8 | 0.96 |
| I | 0.00 | 0% | 0.8 | 0.00 |
| K | 0.53 | 3% | 0.8 | 0.42 |
| L | 0.68 | 4% | 0.8 | 0.54 |
| M | 0.00 | 0% | 0.8 | 0.00 |
| N | 0.00 | 0% | 0.8 | 0.00 |
| **Total for minor subwatersheds** | **3.80** | **23%** | **-** | **3.15** |

### *4.2.2 Road Ditch improvements*

As described in Section 3.2.3.1, there may be limited opportunity for ditch and road improvements around Partridge Lake that would achieve an appreciable phosphorus load reduction. However limited, with strategic design and aggressive maintenance, PLPOA may chose to pursue this type of management measure.

There are approximately 3,500 linear feet of Partridge Lake Road that could be improved to promote the containment of sediment particles present in stormwater runoff (refer to Figure 3-9). Phosphorus export from roadways can be roughly estimated using the following calculation contained in Maine DEP 1992, to determine pounds of phosphorus exported per 100 feet of road surface on an annual basis:

*Road export (lbs/100 ft) = (Road surface width, including shoulders)*(0.008) + (# of ditches)(0.04)*

The (0.008) and (0.04) are constants in the equation. The number of ditches in this calculation can be zero, one or two. A typical section of Partridge Lake Road is approximately 15 feet wide, with no shoulder and one ditch. Using the above calculation on 3,500 feet of Partridge Lake Road, the annual total phosphorus export from this section of road is approximately 5.6 lbs or 2.5 kg.

### *4.2.3 Street Sweeping*

The performance of street sweepers is variable depending on the type of sweeper, weather during sweeping, and site conditions. Tons of sediment and pounds of phosphorus often turn out to be the same (or close to the same) figure for the following reason: 1 pound = 0.0005 tons and coincidentally there is on average an overall phosphorus concentration of 0.0005 pound of TP per pound of soil. There is a correction factor applied depending on soil particle size (sand = 0.85). This correction factor reflects the fact that soils with higher clay and organic matter contents have a higher capacity to hold nutrients, while sandier soils have a lower nutrient capacity (Michigan DEQ, 1999). For each ton of sand collected from the roads around Partridge Lake, it can be assumed that 0.85 pounds (0.39 kg) of phosphorus will be prevented from entering the lake. Given the narrow width of Partridge Lake Road, an application rate of one cubic yard (1.35 tons) of road sand per mile would be common. If the road sand removal is performed at the recommended time (i.e., before heavy spring rains) on Partridge Lake Road along the lake (which equals approximately one mile), 0.52 kg or phosphorus in the form of road sand will be prevented from entering the lake.

## 4.3 Land Use Changes

Residential development can lead to increased phosphorus export compared to forested lands on a per acre basis. For example, total phosphorus exports from rural residential land use can range from 0.19 to 0.53 pounds per acre on an annual basis, depending on the imperviousness of the site (DES 1996a). In the Partridge Lake watershed, existing residential development is generally concentrated around the lakeshore. There is potential, however, that new development could occur away from the lake, thereby converting forested areas to residential areas. The current zoning of land around Partridge Lake in Littleton is rural residential, which requires a minimum residential lot size of 2 acres for new residential development.

To address potential land use change effects on the impacts to Partridge Lake, a Watershed Coordinator should be hired to assist in researching zoning updates, examining build-out scenarios in the watershed, and assisting with other recommendations in this plan. Once the build-out scenarios are performed, an estimate of phosphorus reductions can be determined.

## 4.4 Internal Loading Treatment

As described in Section 2, the average annual internal phosphorus load in Partridge Lake was calculated as 70 kg/year. The actual amount of phosphorus released into the water column of the lake from the sediments through internal loading will vary on an annual basis. Treatment usually is 100% effective in neutralizing the P source in the hypolimnion.

A Wisconsin study reported that applications in stratified lakes were highly effective and long lasting (Wisconsin DNR, 2003). The percent reduction in controlling internal phosphorus loading was continuously above eighty percent. The study did however find that alum treatment of lakes with high external loading was not effective.

## 4.5 Shoreline and Beach Improvements

As mentioned, many beach owners do not replenish their beaches with fresh sand. Perched beaches were recommended to prevent existing beaches from eroding sand into Partridge Lake. For the purposes of estimating the potential pollutant load reduction from improving beaches, the following assumptions were made. According to DES rules, each beach can only replenish 10 cubic yards of sand every 6 years. Therefore, for every beach along Partridge Lake that is improved by perching, assume that 1.67 cubic yards of sand (10 cubic yards / 6 years) is prevented from entering the lake each year. If dry sand has a density of 100 pounds/cubic foot, then 1.67 cubic yards of sand translates into 2.25 tons or approximately 4500 pounds of sand.

Tons of sediment and pounds of phosphorus often turn out to be the same (or close to the same) figure for the following reason: 1 pound = 0.0005 tons and coincidentally there is on average an overall phosphorus concentration of 0.0005 pound of TP per pound of soil. There is a correction factor applied depending on soil particle size (sand = 0.85). This correction factor reflects the fact that soils with higher clay and organic matter contents have a higher capacity to hold nutrients, while sandier soils have a lower nutrient capacity (Michigan DEQ, 1999).

Of course, not all beaches are replenished every six years and not all 10 yards of sand erodes into the lake. Using this equation as a rough estimation, approximately 1.91 lbs (0.87 kg) of phosphorus will not enter Partridge Lake per year for each beach that is improved. There are currently 34 residential beach locations around Partridge Lake (personal communication, D. Goudie). These locations vary in size from 6 feet of shore up to approximately 30 feet of shore. Very few of these have had sand brought in over the last ten or more years.

## 4.6 Homeowner Education

The Outreach and Education efforts conducted in support of this watershed based plan are presented in Section 6. The primary tools implemented in the Partridge Lake Watershed to date include a Lake Guide and a Septic Survey. Each has stressed the importance of phosphorus reduction in the watershed. In particular, the Lake Guide presented several suggestions for watershed residents to limit their household water and associated phosphate use, as well as recommendations related to septic system maintenance, land use practices, and shoreline/beach maintenance.

Through the development of this plan, a true sense of watershed stewardship was displayed by residents involved. It would be reasonable to assume that the educational and outreach efforts would have an effect on reducing the phosphorus use in the watershed. Predicting the effect of these practices in reducing the phosphorus load to the lake can be roughly estimated. For this plan, it was estimated that the education measures would result in a 5% reduction in watershed phosphorus loading through avenues such as reduced detergent use, reduced use of lawn fertilizers, and more judicious upkeep of septic systems.

# 5 TECHNICAL & FINANCIAL ASSISTANCE NEEDED

The estimate of financial and technical assistance required has taken into account the installation, operation, and maintenance of the BMPs; the monitoring, data analysis, and data management activities; continued educational and outreach efforts; and administration and management services.

## 5.1 Financial Assistance

Initial funding has been secured to prepare this Watershed Based Plan and in-kind matching services are being provided by PLPOA and the Town of Littleton. A Watershed Assistance Grant of $10,000 has been obtained to provide funding towards design and installation of Road BMP(s) in the watershed.

Table 5-1 presents the estimated costs for implementing NPS phosphorus reduction management measures for surface water, groundwater, and in-lake management for Partridge Lake based on 2005 dollars. The costs for various options for proprietary stormwater controls were further detailed in Section 3.

**Table 5-1: Estimated Financial Assistance Required for Partridge Lake BMP Implementation.**

| Task | Cost Estimate |
|---|---|
| Hire Watershed Coordinator (Zoning Updates) | $15,000 |
| **Stormwater BMPs** | |
| Design and Implement Road BMPs | $10,000 |
| Priority Tributary BMPs | |
| Tributary J | $40,000 |
| Tributary D | $33,750 |
| Tributary G | $8,000 |
| Tributary A | $40,000 |
| Minor Tributaries (each) | $8,000 each |
| Beach Improvements (per beach) | $2,000 each |
| **Groundwater** | |
| Individual septic system improvements | $5,000 - $30,000 each |
| Cluster system for Group 1 (12 homes) | $300,000 |
| Cluster system for Group 2 (8 homes) | $200,000 |
| Community Education (Septic Survey/Lake Guide) | $10,000 |
| **In-Lake Management** | |
| Alum Treatment (Phosphorous Inactivation) | $70,000-80,000 |

Enhanced TP-removal filters for septic systems will have cost characteristics similar to conventional systems except in the initial and subsequent replacement of the enhanced media. The capital cost would vary between $5,000 and $11,000 (EPA 2002a). The high end of the cost range for the individual septic system improvements can be variable and were based on estimates provided in DES, 2007.

Costs of alum application are primarily dependent on the form of alum used (wet or dry), dosage rate, area treated, equipment rental or purchase, and labor. Liquid alum has been used when large alum doses were needed. The surface area of Partridge Lake is 104 acres; however, it is likely that the alum treatment will only be applied to the hypolimnion layer of the lake, which is approximately 30-50 acres. The cost estimate for this treatment in 2005 was $70,000–80, 000 (DES, 2007).

## 5.2 Technical Assistance

The Town of Littleton has committed to provide equipment and manpower to assist with road BMP construction and maintenance. The town also has the capabilities (vacuum truck) to provide catch basin-type clean-out maintenance. PLPOA has provided manpower to complete septic survey, develop, publish and disseminate the Lake Guide, and review the draft Watershed Based Plan. In addition, PLPOA will continue sampling for the VLAP and will provide monitoring support for road BMP conditions.

DES will provide technical guidance, additional field support, and laboratory services to support the monitoring component.

# 6 EDUCATION AND OUTREACH

## 6.1 Partridge Lake Watershed Partnership

To help the PLPOA achieve their goals and objectives identified in this plan, the PLPOA has organized a watershed partnership between themselves, the Town of Littleton, and the DES. A kick-off partnership meeting was held on June 1, 2006 in Littleton, NH to discuss the overall watershed planning process, results of the one-year diagnostic study, to obtain any additional background information, and to identify and solicit input on major issues of concern within the watershed, including the potential causes and sources of any concerns.

A partnership meeting was conducted in fall 2007 order to inform the interested public in the watershed based plan process and to present, for feedback, preliminary ideas for BMPs. Through this meeting, the community acceptance factor for each alternative was determined.

In addition to the Partnership, PLPOA has prepared a Lake Guide and septic survey for public outreach and education. The objectives of the public outreach program will directly support the watershed management goals and implementation of the watershed management plan.

## 6.2 Lake Guide

Additional outreach and education efforts included the development of a "Lake Guide" by the PLPOA for distribution to watershed residents. Among other things, the Lake Guide stresses the importance of septic system health, and watershed residents will be educated on methods to reduce and manage stormwater runoff thereby reducing phosphorus loading to Partridge Lake. The Lake Guide was distributed in July 2007.

PLPOA has conducted the following tasks in development of the Lake Guide:

- Research and outline relevant materials.
- Outline and Draft Waterfront and Watershed property owners guide for DES review.
- Finalize Waterfront and Watershed property owners guide for printing.
- Distribute Waterfront and Watershed property owner's guide, through mailing and water quality workshop.

## 6.3 Septic Survey

A septic system survey of shoreline and watershed residents was conducted by the PLPOA. The PLPOA prepared the survey with guidance from DES. The survey was disseminated in July 2007. The data collection and analysis was completed in December 2007. The results of the survey are presented in Appendix 1, and were used to develop the recommendations in this plan related to reducing phosphorus loading from septic systems.

# 7 IMPLEMENTATION SCHEDULE AND MILESTONES TO MEASURE PROGRESS

The schedule will include a timeline of when each phase will be implemented and accomplished, as well as the organization responsible for implementing the activity. In addition, the schedule will be broken down into increments that can be reasonably tracked and reviewed.

The completion of this Watershed Based Plan will serve as verification that the following milestones have been achieved: Organize a watershed partnership; Hold one public meeting to hear watershed concerns; Research and summarize data to characterize the watershed; and submit the plan to the partnership member (DES, PLPOA and the Town of Littleton). Additional milestones are listed below.

<u>Phase 1 - Short-term (through 2008)</u>

Tasks/Milestones under Phase 1 include:

- Organize a watershed partnership
- Conduct a public meeting
- Draft and finalize Watershed Based Plan to meet EPA requirements
- Draft, finalize and distribute Lake Guide
- Conduct water quality workshop
- Select, design, and construct Stormwater BMP(s)
- Examine developing zoning overlay

<u>Phase 2 – Mid-term (2008 - 2011)</u>

Tasks/Milestones under Phase 2 include:

- Investigate/implement septic system management measures
- Monitor results of Stormwater BMP(s)
- Evaluate additional Stormwater BMP(s) and secure funding for installation
- Implement homeowner BMPs to decrease groundwater phosphorus loading
- Present zoning overlay district and provide resident outreach

<u>Phase 3 - Long-term (2012 - 2016)</u>

Tasks/Milestones under Phase 3 include:

- Implement in-lake alum treatment to address internal loading

- Upgrade septic systems to address phosphorus loading to groundwater
- Enforce zoning overlay codes
- Monitor surface and groundwater to determine phosphorus reductions

**Table 7-1: Partridge Lake Watershed Based Plan Task/Milestone Schedule.**

| Task/Milestone | Timeline |
|---|---|
| | |
| **Phase 1** | |
| Organize Watershed Partnership | June 2006 |
| Distribute Lake Guide | Summer 2007 |
| Conduct Septic Survey | Summer/Fall 2007 |
| Public Meeting | Fall 2007 |
| Examine Developing Zoning Overlay | Summer 2008 |
| Water Quality Workshop | Summer 2008 |
| Implement Stormwater BMP(s) | Summer 2008 |
| Finalize Watershed Based Plan | December 2008 |
| | |
| **Phase 2** | |
| Implement homeowner BMPs | 2008 - 2011 |
| Septic System Improvements | 2008 - 2011 |
| Present zoning overlay district | 2008 - 2011 |
| Monitor results of Stormwater BMP(s) | 2008 - 2011 |
| | |
| **Phase 3** | |
| In-lake Alum Treatment | 2012 - 2016 |
| Surface and Groundwater Quality Monitoring | 2012 - 2016 |
| Upgrade Septic Systems | 2012 - 2016 |
| Enforce Zoning/Development Codes | 2012 - 2016 |

Table 7-2 displays a cost analysis for various management measures presented in this Watershed Based Plan to address phosphorus loading through surface water, groundwater and internal loading pathways. This table may be used to determine the most feasible and cost effective measures for implementation.

**Table 7-2: Partridge Lake Phosphorus Reduction Implementation Summary.**

| Estimated Source Contributions | | | Implementation | | | | |
|---|---|---|---|---|---|---|---|
| **Source** | **Location** | **Est. Annual P load (kg)** | **Treatment Measure** | **Removal Efficiency** | **Est. Load Reduction (Kg)** | **Estimated Cost** | **Cost per Kg reduced** |
| Stormwater - Tributaries | Tributary J (major) | 3.9 | StormTreat or Aqua-Filter | 80% | 3.12 | $40,000 | $12,821 |
| | Tributary D (major) | 3.2 | Aqua-Filter | 80% | 2.56 | $33,750 | $13,184 |
| | Tributary G (major) | 2.9 | StormTreat | 80% | 2.32 | $8,000 | $3,448 |
| | Tributary A (major) | 2.6 | Aqua-Filter | 80% | 2.08 | $40,000 | $19,231 |
| | Tributary B | 0.12 | Generic | 80% | 0.08 | $8,000 | $100,000 |
| | Tributary E | 0.94 | Generic | 80% | 0.72 | $8,000 | $11,111 |
| | Tributary F | 0.36 | Generic | 80% | 0.32 | $8,000 | $25,000 |
| | Tributary H | 1.17 | Generic | 80% | 0.96 | $8,000 | $8,333 |
| | Tributary K | 0.53 | Generic | 80% | 0.42 | $8,000 | $19,048 |
| | Tributary L | 0.68 | Generic | 80% | 0.54 | $8,000 | $14,815 |
| Roads | Partridge Lake Road | 2.5 | Stone-lined ditches | - | - | $10,000 | - |
| Shoreline Erosion | Beach Sand | 0.87 | Perched Beach | 100% | 0.87 | $2,000 | $2,300 |
| Groundwater | Lake-wide | 60.6 | Individual septic improvements | 50% | 1.28 (per household) | $30,000 (high-end) | $23,438 |
| | Cluster 1 | 18.7 | Community System/Retrofits | 50% | 9.34 (12 households) | $300,000 | $16,067 |
| | Cluster 2 | 8.8 | Community System/Retrofits | 50% | 4.40 (8 households) | $200,000 | $23,748 |
| Internal Loading | Hypolimnion | 70.0 | Alum Treatment | 100% | 70.00 | $80,000 | $1,143 |
| Residential | Lake-wide | 39.8 | Education | 5% | 1.99 | $10,000 | $5,025 |
| | | | Watershed Coordinator | 10% | 4.0 | $15,000 | $3,750 |

Notes: See Section 4 for a description of load reduction estimates for each management measure.

# 8 CRITERIA TO DETERMINE PROGRESS IN ATTAINING WATER QUALITY STANDARDS & LOAD REDUCTIONS

Using the milestones and schedule presented above, a set of criteria with interim target values are defined to determine whether progress is being made toward reducing pollutant loads. For this Project, there are environmental criteria which will be used to evaluate the effectiveness of the combined management measures outlined in this plan. Criteria can also include social indicators such as the public response to the education and outreach tools planned for the Partridge Lake watershed, for example.

The ultimate criteria used to measure the progress of this project are the water quality parameters deviation from attaining the Water Quality Standards. DES designated Partridge Lake on the Draft 303(d) list as an impaired waterbody because of a declining trend for dissolved oxygen levels. If the lake exhibits a stable or improving trend for dissolved oxygen, then DES could find the lake is attaining State water quality standards and remove Partridge Lake from the impaired waterbodies list.

Interim water quality targets will be verified by direct measurements obtained through sampling or further analysis as determined through the Watershed Based Plan. For example, one of the Project's goals is to reduce external loading of phosphorus into the lake. VLAP data will be monitored to track this goal. Criteria will be tied to actual levels of TP measured throughout the lake and the number of algae blooms observed. Water quality indicators include phosphorus concentrations in the lake and tributaries, algal concentrations and reports of potential algal blooms, and dissolved oxygen levels in the hypolimnion of the lake. Interim water quality criteria for Partridge Lake are presented in Table 8-1.

Field scale pollutant load reduction estimates will be completed for the BMP sites using EPA recommended methods. These field scale estimates will yield some useful indication of progress. Tributary-by-tributary data collected after the BMP implementation will be compared with similar data collected in 2001. TP loading through surface run-off to Partridge Lake will have decreased consistent with predicted BMP efficiencies at the end of Phase 1.

Regarding dissolved oxygen in the bottom layer of the lake, thermal stratification, or layering, is typical for a lake with the size and depth of Partridge Lake. This may prevent the lake from mixing during the summer, eventually leading to a naturally occurring deficit of bottom dissolved oxygen due to the continuous consumption of oxygen during microbial decomposition. Therefore, it may not be appropriate to evaluate the effectiveness of this Project on hypolimnetic dissolved oxygen levels. Actual inputs of TP through surface water and TP values of each lake layer may be the most appropriate criteria.

These measures will be used to determine if the existing management approach requires revisions. A useful tool when evaluating the BMP effectiveness will be the EPA's *Urban Stormwater BMP Performance Monitoring Guidance Manual*.

In addition to the water quality indicators, the social indicators used to measure progress will include:

- Number of people responding to the septic survey,
- Number of people receiving the Lake Guide,
- Feedback received from the Lake Guide in the form of questions, etc., and
- Attendance at a Water Quality Workshop.

The success of BMP construction will be verified by complete photo documentation in accordance with Standard Operating Procedures developed by DES. Photo documentation of the road/ stormwater BMPs will be obtained prior to and after completion.

**Table 8-1: Water Quality Indicators to Determine Progress in Removing Lake from 303(d) List**

| **Indicator** | **Target Value** | **Comments** |
|---|---|---|
| # of Cyanobacteria Blooms | 0 | Ideally would like none to occur. |
| GW inputs of TP | Decrease by 25% | (25% of 23.4) Will need additional monitoring after education effort and any septic remedial program. |
| SW inputs of TP | Decrease by 25% | Monitor tributaries after specific BMP implementation. |
| TP, hypolimnetic | < 50 µg/L | In 2006, hypolimnetic TP ranged from 92 µg/L in June (under thermally stratified conditions) to 20 µg/L in November (under non-stratified conditions). |
| TP, fully mixed, in-lake | < 11 µg/L | Approximates the in-lake concentration based on external load reductions of 10kg TP/year, without internal loading. |
| Conductivity, hypolimnetic | < 75 µmhos/cm | Approximate mean of long-term value in upper layer of the lake. |
| Chlorophyll a | < 5 $mg/m^3$ | In 2006, chlorophyll a concentrations ranged from 3.99 $mg/m^3$ to 13.73 $mg/m^3$. |

# 9 MONITORING COMPONENT

Short term and long term monitoring will be performed under this plan to examine the effectiveness of the management measures implemented in the Partridge Lake watershed. The monitor will consist of:

- Documentation of structural BMP implementation;
- Site specific tributary monitoring after BMP implementation;
- Long-term trend monitoring through VLAP; and
- Potentially sample groundwater after management measures, if appropriate.

The monitoring component will be implemented to determine whether loading reductions are being achieved over time and substantial progress in achieving water quality standards is being made according to the criteria stated above. The key question in determining when and how to monitor should be: "Will the information provided from the monitoring program significantly improve the understanding of the effectiveness of the BMP being monitored?" (EPA, 2005a).

To examine site-specific BMP effectiveness, water quality sampling should be performed. The monitoring conducted will also examine the overall progress in reducing the in-lake phosphorus concentrations. The VLAP monitoring plan will be the primary monitoring tool to assess the effectiveness of the improvements; however the program may be expanded to include monitoring the tributaries or site-specific locations relative to BMP implementation. The feasibility of designing and implementing a comprehensive baseline and storm-event tributary monitoring program will be addressed with the partnership.

Given that we have baseline phosphorus numbers for the 2001 Diagnostic Study and trends from the VLAP program, repetition of the former and continuation of the latter is recommended to monitor the overall performance of the load reduction strategy.

In order to determine the effectiveness of any management measures implemented to address phosphorus loading to Partridge Lake from groundwater sources, it is recommended that groundwater sampling be performed after implementation of the selected management measures. The specifications of the sampling should be modeled after the sampling methods conducted by DES. The timing of sampling should be determined with support from DES. Once improvements are implemented, further study will be required to determine pollutant load reductions through groundwater. Monitoring methods may be modeled after the Baboosic Lake Phase 2 Project.

Partridge Lake Watershed Partnership will prepare a report documenting the estimated nonpoint source pollutant load reduction (sediment and phosphorus) that is achieved due to the implementation of the 319 funded conservation practices at NPS sites in the watershed. The methods to be used were described in Section 4 of this plan. Final estimates will be prepared for all sites unless it is not feasible to apply the method on the site and supporting calculations will be attached.

If is it found that the management measures are not effective at reducing the phosphorus loading to the lake, the Watershed Based Plan will be revised in consultation with DES.

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## APPENDIX 1: 2007 PARTRIDGE LAKE SEPTIC SURVEY AND RESULTS.

# APPENDIX 2: ADDITIONAL SPECIFICATIONS FOR PROPRIETARY STORMWATER BMPS.

## APPENDIX 3: TIME OF CONCENTRATION AND CURVE NUMBER CALCULATIONS.